Indian and Northern Affairs Canada
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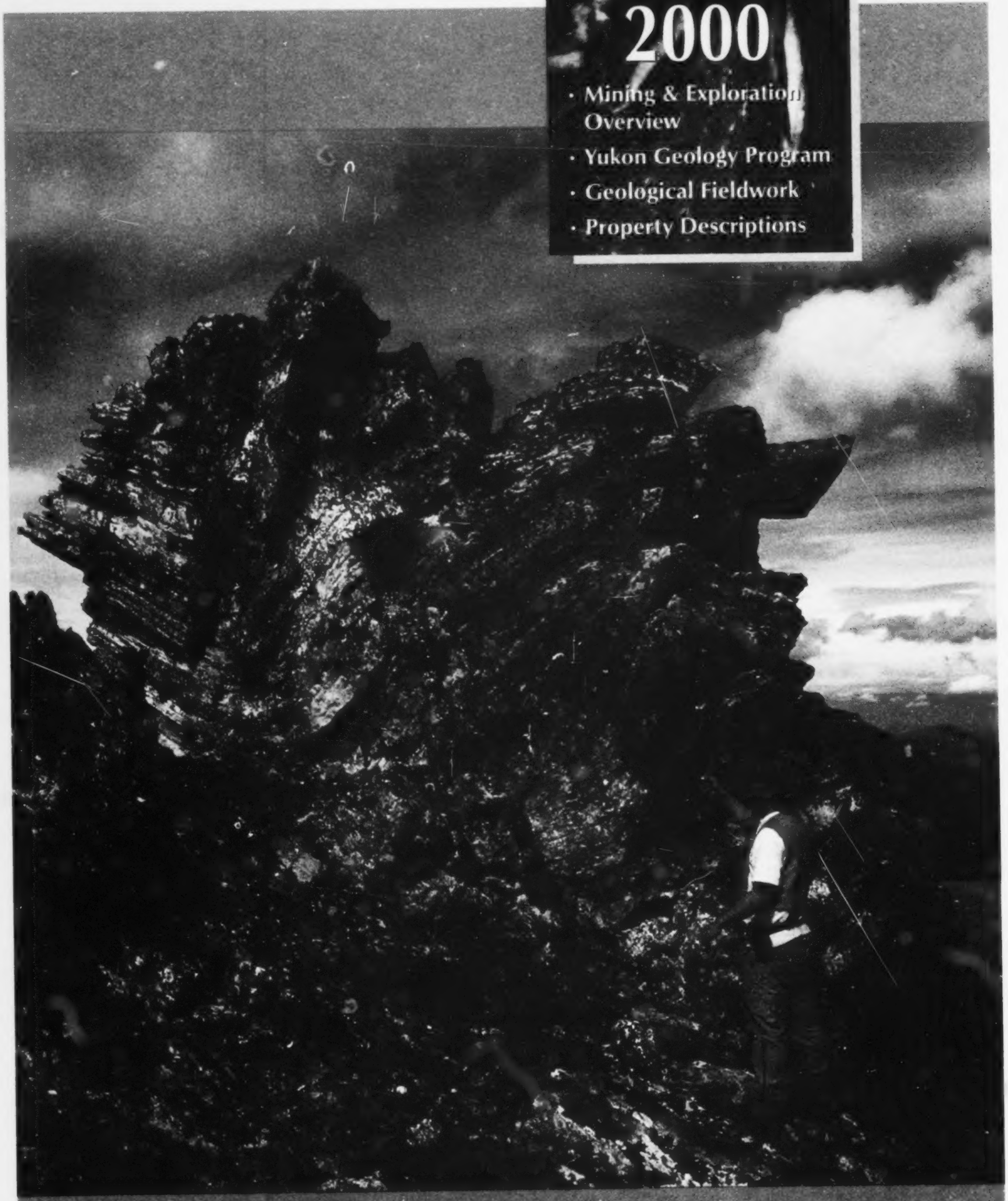
Exploration and Geological Services Division, Yukon Region

YUKON EXPLORATION & GEOLOGY

2000

- Mining & Exploration Overview
- Yukon Geology Program
- Geological Fieldwork
- Property Descriptions



Canada

YUKON GEOLOGY PROGRAM

Yukon Government

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YUKON
EXPLORATION & GEOLOGY
2000

Edited by
D.S. Emond and L.H. Weston

Exploration and Geological Services Division, Yukon
Indian and Northern Affairs Canada

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Front cover photo
Reid Kennedy examines a folded sequence of quartz sandstone and dolostone in the upper part of the Little Salmon succession, Glenlyon map area, central Yukon. Photo by Maurice Colpron.

Front cover photo, background of title tab
Banded sphalerite-galena mineralization showing de-watering structures from Hole A-67 drilled in the Don Valley area at the Howards Pass project. Photo by Mike Burke.

Back cover photo
Bill Wengzynowski, 2000 Yukon Prospector of the Year, at his emerald discovery – the Crown emerald showing – on the Goal-Net property of Expatriate Resources. Bill is also credited with discovery of the Ice deposit (drill-indicated resources are 4.56 Mt grading 1.5% Cu), in the Finlayson Lake volcanogenic massive sulphide district. These are two of many discoveries that Bill has made during his illustrious career with Archer, Cathro and Associates (1981) Ltd. Photo by Mike Burke.

PREFACE

Yukon Exploration and Geology (YEG) is the main publication of Exploration and Geological Services Division of Indian Affairs Canada (DIAND). This is the 23rd volume of the YEG series. It contains up-to-date information on mining and mineral exploration activity, studies by industry, and results of recent geological field studies. Information in this volume comes from prospectors, exploration and government geologists, mining companies and students who are willing to collectively benefit the Yukon's mineral industry. Their assistance and patience is sincerely appreciated.

Maurice Colpron of the Yukon Geology Program ably assisted in the translation and review of French abstracts. Danièle Héon also reviewed some French abstracts. Maurice Colpron, Julie Hunt and Charlie Roots critically reviewed several manuscripts. Julie Hunt coordinated the dedication at the beginning of this volume. Sincere appreciation is extended to Leyla Weston for her diligence and enthusiasm in co-editing this volume. Wynne Krangle and Peter Long of K-L Services also continue to provide excellent service in putting this production together, including editing suggestions, design of diagrams, volume layout, and working under the pressure of a tight deadline.

The 2000 volume has four parts. The first – **Mineral Industry** – includes overview of **Mining and Exploration** in the Territory. The second part – **Government** – outlines the activities and organization of the Yukon Geology Program. This section also includes an update on the Yukon Mining Incentives Program, and announcements of the second Mining Land Use Reclamation Awards, the Robert E. Leckie Awards. The third part – **Geological Fieldwork** – contains reports describing regional mapping, and more detailed geological, geochemical, geophysical, geochronological, paleontological, paleomagnetic and placer deposit studies. The last part – **Property Descriptions** – is a collection of geological reports of mineral occurrences with recent exploration advances and is authored by industry and government geologists, as well as university students.

This volume is dedicated to Chris Guichon, a well known, well loved and highly respected helicopter pilot who served many people in the mining and exploration community.

We welcome any input or suggestions that you may have to improve future YEG publications. Please contact me at (867) 667-3203 or by email at emondd@inac.gc.ca.

Diane Emond

Thanks to Trans North Helicopters, Nancy Guichon, Harmen Keyser, Al Doherty, and Roger Hulstein for providing photographs.

Dedication

Chris Guichon
1957-2000

Gone flying...

Every once in a while, a person comes along whose enthusiasm and love of life are so remarkable that their memory will never be forgotten. Our friend Chris Guichon, who died on June 22, 2000 in a tragic helicopter crash, was one of those people.

Honesty, integrity, dedication, skill, selflessness and a positive attitude were just a few of Chris's attributes. He was a true friend to many people involved in Yukon exploration and aviation.

Chris will be remembered by all of us for his caring attitude and his wonderful good humour. He touched many of us in the work that we shared with his great generosity and his genuine interest in others. He enjoyed flying immensely and his excellent skills made our work much easier. His great enthusiasm and calm while flying were matched by caring and kindness towards those he worked with. We always felt safe and had fun while flying with Chris. He was an extraordinary pilot and a wonderful person.

We think of him often and miss him enormously.

We take this occasion to also remember those that died with Chris, and all those who have lost their lives in the pursuit of mineral exploration.

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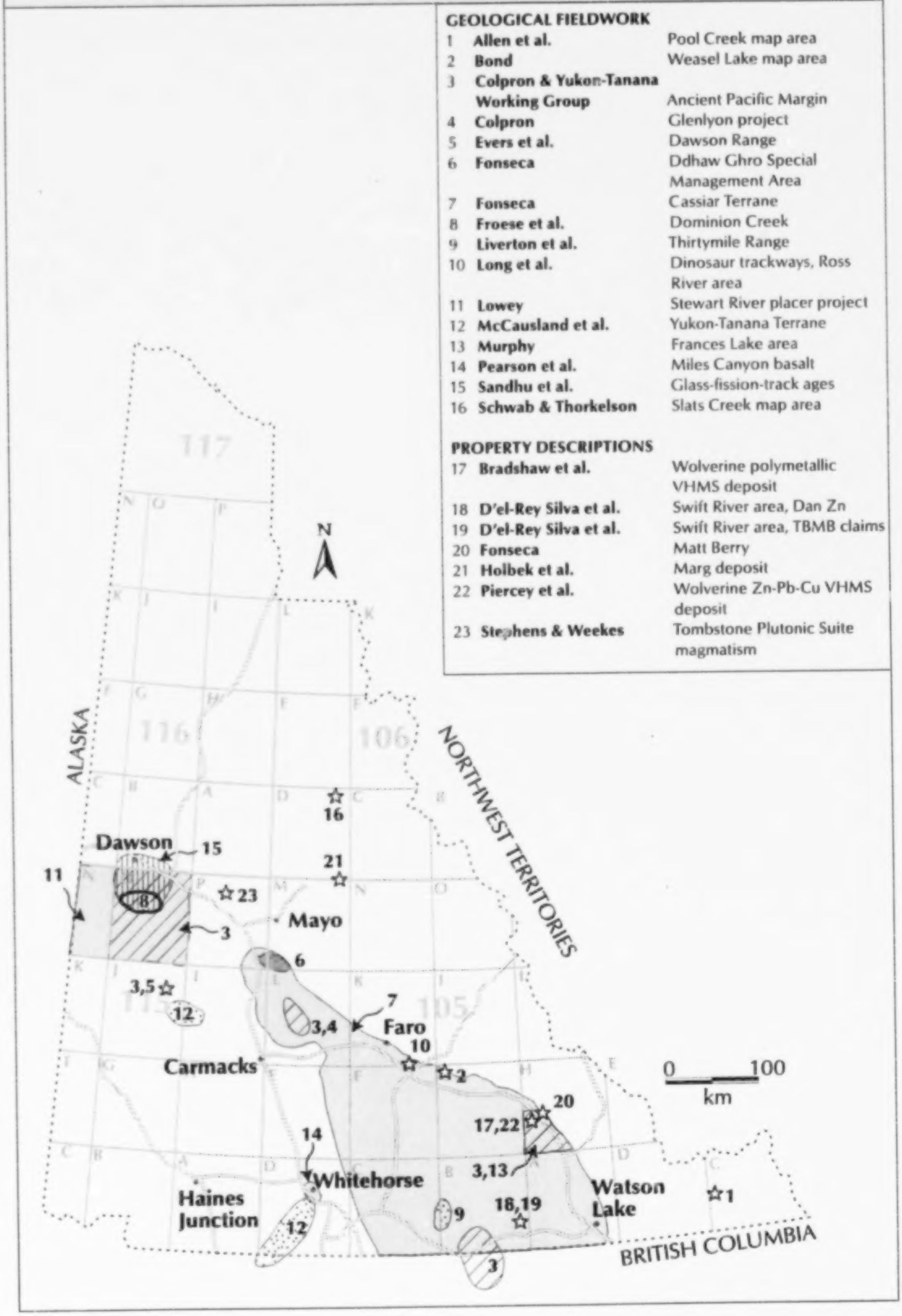

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MINERAL INDUSTRY

Yukon mining and exploration overview, 2000

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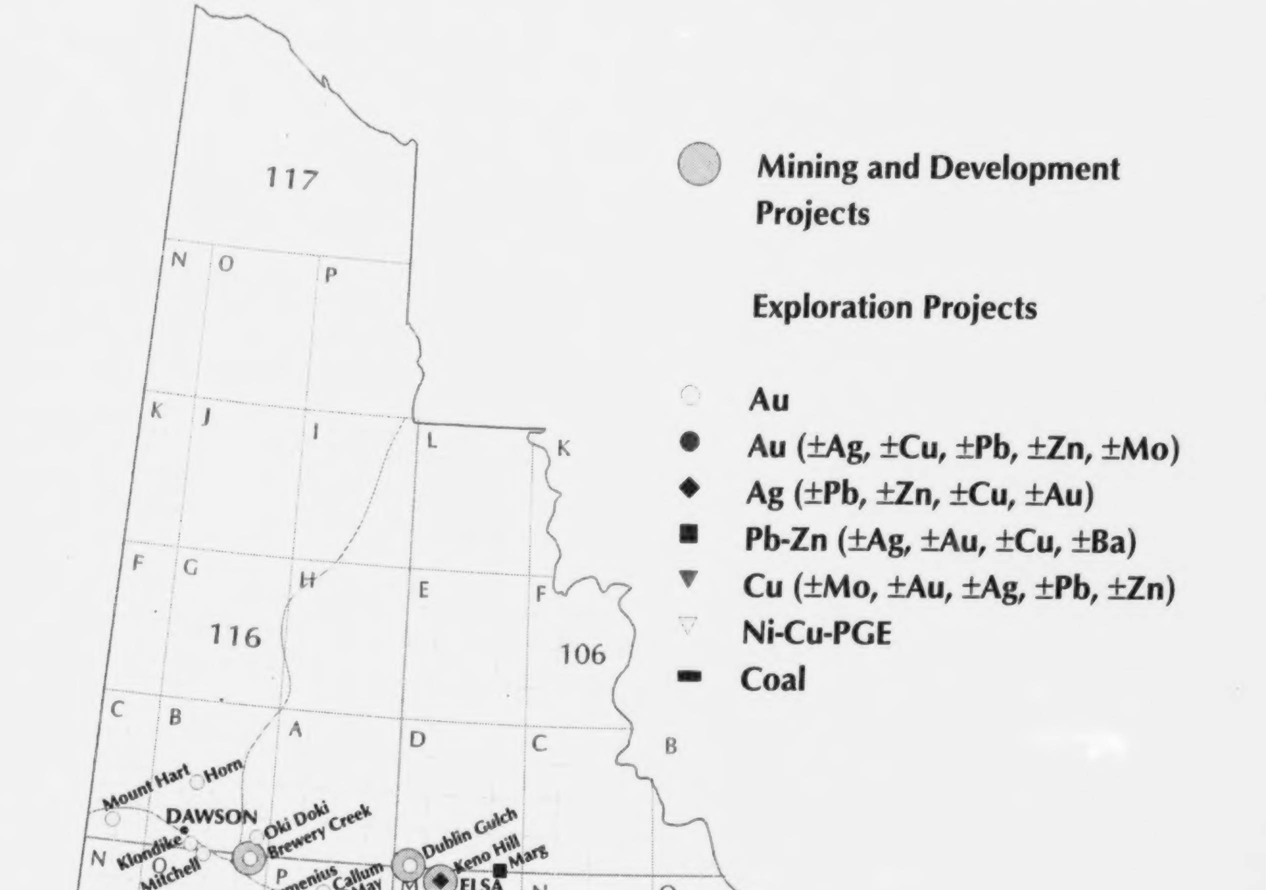
Mining and Development Projects
Exploration Projects
○ Au
● Au (±Ag, ±Cu, ±Pb, ±Zn, ±Mo)
◆ Ag (±Pb, ±Zn, ±Cu, ±Au)
■ Pb-Zn (±Ag, ±Au, ±Cu, ±Ba)
▼ Cu (±Mo, ±Au, ±Ag, ±Pb, ±Zn)
▽ Ni-Cu-PGE
▬ Coal
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Dublin Gulch
Keno Hill
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Premo
Ladue
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Longline
Eureka/Armenius
Clear Creek
Callum
May
McQuesten
Sinister
Aurex
MAYO
Swan
P7P
Coffee Creek
Canadian Creek
Rude Creek
Minto
Carmacks Copper
Revenue
Andrew
Nug
FARO
Faro
Grew Creek
ROSS RIVER
Howards Pass
CARMACKS
Division Mountain
Fox
St.Cyr
Livingstone
Fire/Ice
Kudz Ze Kayah, GP4F
Wolverine
Red Line
Goal/Net
Hy
Sprogge/Sun
AR
Burwash
Klu
HAINES JUNCTION
WHITEHORSE
Hat
Wheaton
Sa Dena Hes
QB
Blue Heaven
C.I.
Mor
WATSON LAKE

Figure 1. Location of active Yukon mines, development and exploration projects in 2000. Not all projects are shown on the map. Background of the map shows the National Topographic System (NTS) grid.

YUKON MINING AND EXPLORATION OVERVIEW, 2000

Mike Burke[1]
Yukon Geology Program

Burke, M., 2001. Yukon mining and exploration overview, 2000. *In:* Yukon Exploration and Geology 2000, D.S. Emond and L.H. Weston (eds.), Exploration and Geological Services Division, Yukon, Indian and Northern Affairs Canada, p. 2-27.

RÉSUMÉ

Au Yukon, la production minérale s'est poursuivie à la mine d'or Brewery Creek de la Viceroy Resource Corporation, située à l'est de Dawson City. La mine d'or Brewery Creek avait produit 39 936 onces (1 024 408 grammes) d'or à la fin du troisième trimestre 2000 à un coût d'exploitation de 250 $US l'once. La production pour l'année devrait être de l'ordre de 50 000 onces (1 555 150 grams) d'or. La Minto Exploration a poursuivi la mise en œuvre de son projet Minto de mine de cuivre, d'or et d'argent. Le projet est entièrement approuvé, et les étapes du financement et de la mise en production pourrait être franchies dans un an.

Les travaux d'exploration minérale dans le territoire ont portés sur une vaste gamme de cibles pour les métaux communs et précieux; plusieurs projets ayant produit des résultats importants. Les dépenses d'exploration pour 2000 sont évaluées à 8,8 millions $C, en baisse par rapport aux 9,5 millions dépensés en 1999. La faiblesse des prix des métaux et l'absence de participation d'intérêts spéculatifs dans le secteur minier secondaire sont les principaux facteurs responsables de cette baisse. Les nouvelles découvertes peuvent aussi entraîner une hausse des dépenses. Ce fut le cas récemment, lorsque les dépenses d'exploration ont atteints les 54 millions $C en 1996, suite à la découverte du gisement de sulfures massifs volcanogéniques (SMV) de Kudz Ze Kayah par la Cominco Ltd. Une autre découverte semblable pourrait survenir au Yukon où plusieurs projets d'exploration ont produits des résultats de forage concluants. Toutefois, la difficulté de réunir les capitaux requis a fait dérapé cette ruée potentielle. Au total, 2379 claims ont été jalonnés dans l'an 2000, et le nombre de claims en règle avait chuté à 56 240, une baisse importante par rapport à l'année précédente.

En l'an 2000, l'exploration minérale a porté tant sur les métaux communs que précieux. Les travaux d'exploration pour l'or ont encore portés essentiellement sur les gisements d'or associés aux intrusifs de la « ceinture aurifère de Tintina ». Les forages au diamant ont porté sur des filons à forte teneur et des cibles à fort tonnage sur les propriétés suivantes : propriété Longline sur la frontière Yukon-Alaska dans le centre du Yukon, skarn à forte teneur sur la propriété Horn près de Dawson, zone bréchique quartzifère dans le skarn de Clear Creek et zones de substitution à McQuesten, près de Keno Hill, et zones de substitution et structurales sur la propriété Sun/Sprogge dans le sud-est du Yukon. Les résultats des forages ont été concluants sur plusieurs propriétés. L'exploration pour les

---

[1] *burkem@inac.gc.ca*

éléments du groupe du platine (EGP) fut surtout concentrée dans la zone ultramafique de Kluane, dans le sud-ouest du Yukon. Les programmes menés dans cette zone visaient à préciser des cibles de forage pour 2001. Plusieurs autres projets de reconnaissance ont aussi été réalisés dans d'autres régions du Yukon qui sont promettrices pour les EGP.

L'exploration pour les métaux communs a surtout porté sur des gisements de SMV. L'acquisition du gisement de Kudz Ze Kayah par Expatriate Resources Ltd., qui détient déjà le gisement de Wolverine, a relancé les activités d'exploration dans la région de Finlayson Lake et une étude de faisabilité concluante a permis de progresser vers l'étape de la mise en valeur. La prospection dans les autres régions de SMV prometteuses a produit des résultats fort encourageants, notamment sur la propriété *'Fire and Ice'* dans la zone volcanique des monts Pelly et sur la propriété Mor dans le terrane Yukon-Tanana dans le sud du Yukon. La Copper Ridge Exploration a mené un vaste programme sur le gisement sédimentaire exhalatif de Howards Pass dans l'est du Yukon. Le programme visait surtout à évaluer les possibilités hydrométallurgiques et de nouveaux scénarios énergétiques (gaz naturel), qui permettraient de réduire considérablement les coûts d'immobilisation et d'exploitation. Le gisement d'Howards Pass est le plus gros dans le nord de la Cordillère canadienne; il renferme une des plus fortes concentrations de corps stratiformes de zinc et plomb, logés dans des sédiments, dans le monde. L'exploration a aussi porté sur la recherche de gisements de cuivre et or porphyriques dans le chaînon de Dawson et de la ceinture cuprifère de Whitehorse, un type de cible qui n'a pas suscité beaucoup d'intérêt au Yukon ces dernières années.

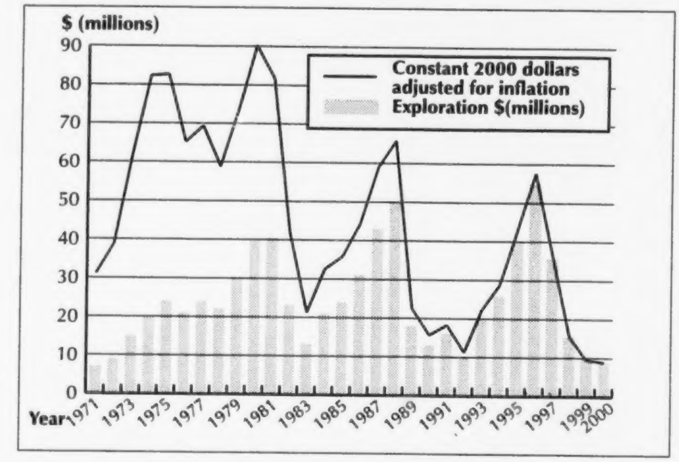


Figure 2. *Yukon exploration expenditures: 1971-2000.*

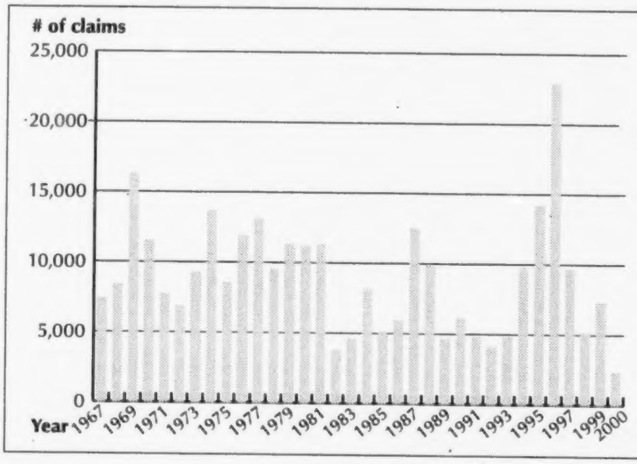


Figure 3. *Quartz claims staked: 1967-2000.*

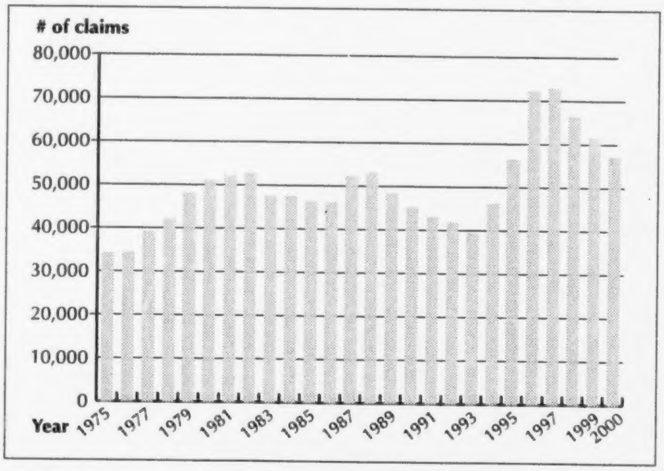


Figure 4. *Quartz claims in good standing: 1975-2000.*

INTRODUCTION

Mineral production in the Yukon continued at Viceroy Resource Corporation's Brewery Creek gold mine located east of Dawson City. The Brewery Creek mine produced 32,936 ounces (1,024,408 grams) of gold to the end of the third quarter of 2000 at a cash operating cost of US$250 per ounce. Production for the year is projected to be in the range of 50,000 ounces (1,555,150 grams) of gold. Minto Exploration continued with development of the Minto copper-gold-silver project. The project is fully permitted, and with financing could be completed and in production in one year.

Mineral exploration in the Territory was directed at a wide range of base and precious metal targets with several projects (Fig. 1) producing significant results. Exploration expenditures for 2000 are estimated to be $8.8 million, down from $9.5 million spent in 1999 (Fig. 2). Poor commodity prices and the lack of speculative investors participating in the junior mining sector are the main contributors to this decrease. An increase in exploration can be fueled by new discoveries. A recent example of this is the peak in exploration expenditures of $54 million spent in 1996 following Cominco Ltd.'s discovery of the Kudz Ze Kayah volcanogenic massive sulphide (VMS) deposit. The Yukon may be on the brink of another such discovery with several exploration projects returning significant drilling results. However, the difficulty in raising capital has transformed this potential rush into a crawl. A total of 2379 claims were staked in the year 2000 (Fig. 3), and claims in good standing had dropped to 56,240 (Fig. 4), a significant decrease from the previous year.

In an effort to bolster declining exploration expenditures and demonstrate its commitment to the mineral industry, the new Yukon government increased funding to the Yukon Mining Incentive Program by $250,000 to $628,000. The government also increased the Yukon Mineral Exploration Tax Credit from 22% to 25%, effective April 1, 2001 and extended the eligibility period to March 31, 2002.

Exploration in 2000 was divided equally between the search for base and precious metals. Gold exploration was once again dominated by the search for intrusion-related gold deposits within the Tintina gold belt. Targets diamond drilled at the following properties included: high-grade veins and bulk tonnage targets at the Longline property on the Yukon-Alaska border in central Yukon, high-grade skarn at the Horn property near Dawson, a quartz-breccia zone at Clear Creek, skarn and replacement zones at McQuesten, near Keno Hill, and replacement and structural zones on the Sun/Sprogge property in southeastern Yukon. Significant results from drilling were obtained on several of the properties. Exploration for platinum group elements (PGE) was conducted mainly in the Kluane ultramafic belt. Programs in the belt were directed at refining drilling targets for the 2001 exploration season. Several other reconnaissance projects were also directed at other PGE-prospective areas in Yukon.

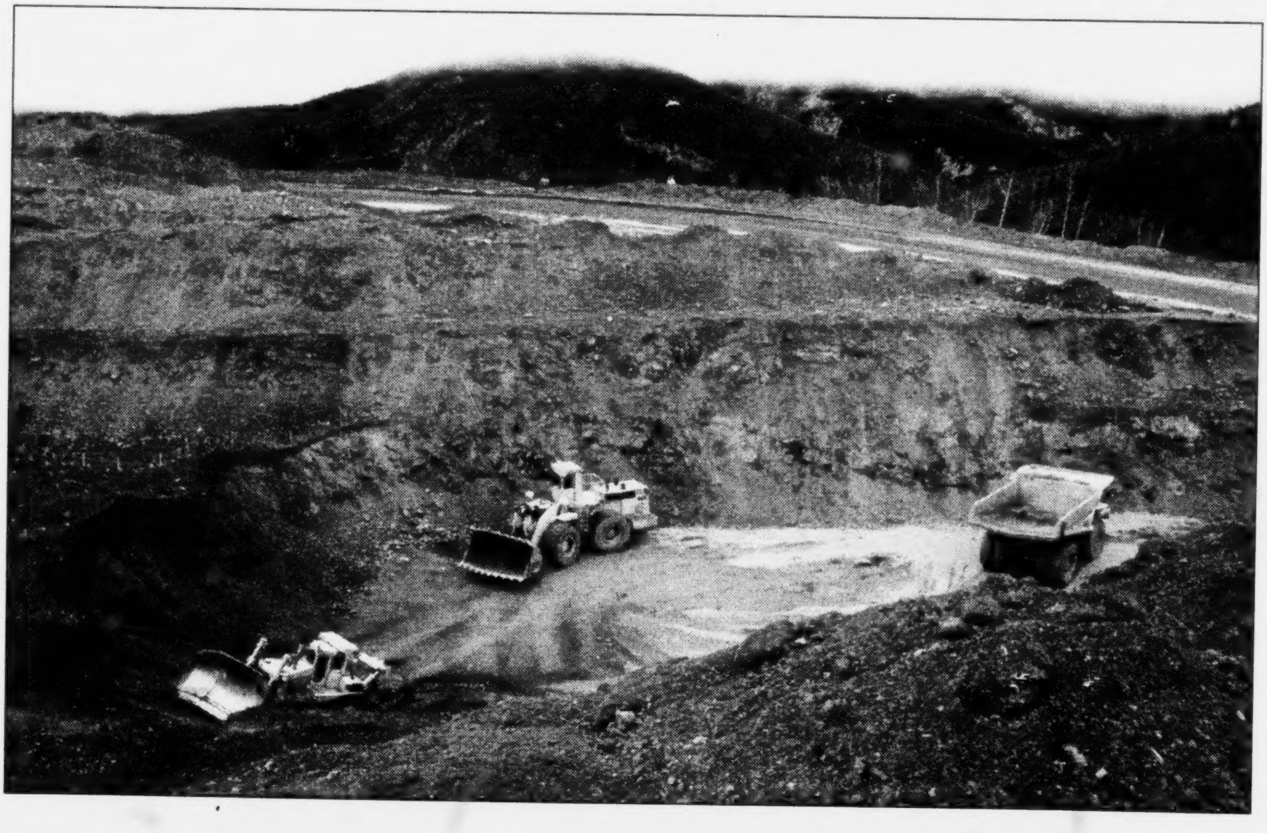
Base metal exploration was dominated by the search for volcanogenic massive sulphide (VMS) deposits. The consolidation of the Kudz Ze Kayah and Wolverine deposits by Expatriate Resources rekindled exploration in the Finlayson Lake district and has significantly advanced the projects towards development with a positive pre-feasibility study. Exploration in other prospective VMS districts, including the Fire and Ice property in the Pelly Mountains volcanic belt and the Mor property in

Yukon-Tanana Terrane in southern Yukon, generated exciting results. Copper Ridge Exploration conducted a major program at the Howards Pass sedimentary-exhalative deposit in eastern Yukon. The main focus of the program was to test for open-pit potential and to evaluate hydrometallurgy and new power options (natural gas), which have the potential to reduce capital and operating costs significantly. Howards Pass is the largest deposit in the northern Canadian Cordillera, which contains one of the world's largest concentrations of sediment-hosted stratiform zinc-lead mineralization. Porphyry copper-gold deposits, which have not received much attention in the Yukon in recent years, were also subject to exploration in the Dawson Range and in the Whitehorse Copper Belt.

MINING AND DEVELOPMENT

Viceroy Resource Corporation's **Brewery Creek gold mine** (Yukon MINFILE, 1997, 116B 160) was Yukon's only active hard-rock mine in 2000. The mine is a bulk tonnage, heap leach operation located 57 km east of Dawson City. Intrusive-related gold mineralization is hosted by intrusions of the mid-Cretaceous Tombstone Plutonic Suite, and Silurian to Carboniferous clastic metasedimentary rocks of the Steel Formation and the Earn Group. Production to the end of September yielded 32,936 ounces (1,024,408 grams) of gold at a cash operating cost of US$250 per ounce. Mining operations removed a total of 3.291 million tonnes of material, including 1.68 million tonnes of ore from four open pits: Blue, Lucky, Pacific and Moosehead (Fig. 5). A total of 1.933 million tonnes of ore was delivered to the heap leach pad, grading 1.72 g/t Au. Recoveries in the ore currently being mined

Figure 5. Mining operations at the Moosehead open-pit. Brewery Creek produced ore from four open pits in 2000.



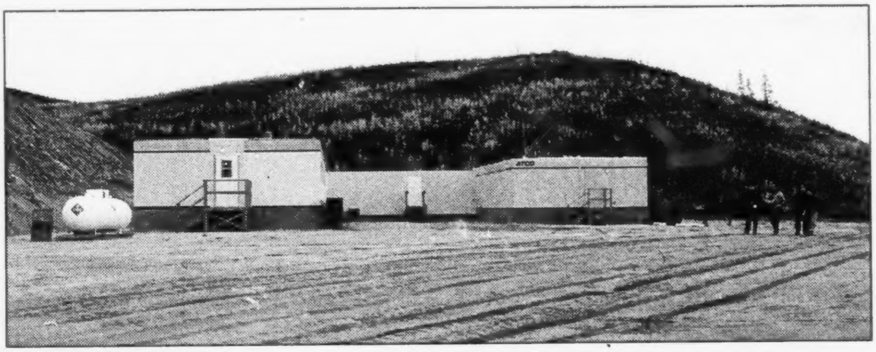


Figure 6. *Mine development at the Minto project included completion of the 54-person camp and kitchen/diner/change-house complex.*

are estimated at 65% based on experience from 1999 when the mine produced 48,164 ounces (1,498,045 grams) of gold, a 35% production shortfall. Lower recoveries are a result of mining deeper ore in the transitional (oxide to sulphide) zone and from lower than expected recoveries in higher grade sedimentary ores. Total production for 2000 is projected to be 50,000 ounces (1,555,150 grams) of gold at a cash operating cost of US$245 per ounce. Reserves as of December 31, 1999 were 3.1 million tonnes grading 1.59 g/t Au calculated at a US$300 gold price. The heap leach pad, before the onset of mining in 2000, had 3.5 million tonnes of capacity, which was sufficient for two years of production.

Mine development expenditures were approximately $550,000 in 2000. Viceroy Resource Corporation expended $200,000 on solution handling and water-treatment facilities at the Brewery Creek gold mine. Minto Explorations Ltd. incurred the remainder of the mine development expenditures at the **Minto Cu-Au-Ag** project (Yukon MINFILE, 1997, 115I 021, 022). Development at Minto included roadwork, equipment purchases, and completion of the 54-person camp and kitchen/diner/change-house complex (Fig. 6). The proposed mine is located 240 km northwest of Whitehorse and will be developed as a conventional open pit mine and milling operation. The deposit has a mineable reserve of 6.51 million tonnes grading 2.13% Cu, 0.62 g/t Au, 9.3 g/t Ag at a 4.9:1 strip ratio. In 1996, the company concluded a mining venture agreement with ASARCO Inc. (a subsidiary of Grupo Mexico), under which ASARCO can acquire a 70% interest in the project in consideration for providing up to US$25 million for development of the project. The project is fully permitted and, contingent on funding, could be in production within one year.

BASE METALS EXPLORATION

Exploration for base metals focussed mainly on volcanogenic massive sulphide (VMS) targets in various geological settings throughout the Yukon. Other deposit types sought included sedimentary-exhalative targets in Selwyn Basin, carbonate-replacement targets in the Rancheria Ag-Pb district, and Cu-Au porphyry targets in the Dawson Range and Whitehorse Copper Belt.

Expatriate Resources has a purchase agreement with Cominco to acquire the **Kudz Ze Kayah** (Yukon MINFILE, 1997, 105G 117) and **GP4F** VMS deposits (Fig. 7), as well as 2800 surrounding mineral claims in the Finlayson Lake VMS district; this is known as the Finlayson Project. Hatch Associates Ltd. completed a pre-feasibility study for Expatriate Resources on the Finlayson Project, which

Figure 7. *Rob Duncan (left) and Terry Tucker (kneeling) of Expatriate Resources examine core from the GP4F deposit stored at the KZK camp.*

Figure 8. *Terry Tucker of Expatriate Resources gives Ken Kagiyama of Dowa Mining Co. Ltd. and Julie Hunt of the Yukon Geology Program an overview of the proposed development plans at the Wolverine project.*

combines probable reserves from the Kudz Ze Kayah (100% Expatriate) and the **Wolverine** (60% Expatriate, 40% Atna Resources Ltd.; Yukon MINFILE, 1997, 105G 072) deposits. Probable reserves used in the study total 14.57 million tonnes grading 7.23% Zn, 1.53% Pb, 0.97% Cu, 184.5 g/t Ag and 1.39 g/t Au. The study indicates, on a 100% equity-financing basis, that the base-case discounted cash flow analysis of the project yields a pretax internal rate of return (IRR) of 39.2% and an after-tax IRR of 31.9%. The project net present value at a 10% discount rate is $255 million pretax and $163 million after tax. The Finlayson project has a payback for the capital cost of two years from the start of production. Capital costs are estimated at $186.5 million with a 15% contingency. Metal prices used in the analysis were US$0.55 per pound zinc, US$0.20 per pound lead, US$0.90 per pound copper, US$5.00 per ounce silver, US$275 per ounce gold with an exchange rate of C$1.00 = US$0.68.

The production plan for the Finlayson Project consists of an open pit at Kudz Ze Kayah producing 3000 tonnes per day, and an underground operation at Wolverine producing 1250 tonnes per day (Fig. 8). The ores will be blended and processed at a 4250 tonne per day facility located at Kudz Ze Kayah. The blending of Kudz Ze Kayah ore and the high-selenium Wolverine ore produces a concentrate that dilutes the selenium content to acceptable levels. Several smelter operators have provided letters of interest for the concentrate products and have provided smelter terms used in the pre-feasibility study.

Expatriate completed seven drill holes in the Lynx zone of the Wolverine deposit along the proposed path of an underground drift, which will be included as part of the feasibility study proposed for 2001. Overall, recent drilling confirmed a previous interpretation of the deposit based on wider spaced drilling conducted in earlier programs. Drilling from the 2000 exploration program will provide detailed information for test mining that is planned as part of the feasibility study.

Exploration potential in the Finlayson Project is considered to be very high. All of the main deposit areas, Wolverine, Kudz Ze Kayah, and GP4F, are open to expansion and additional drilling can upgrade resources in the deposits to the reserve base. The first priority for Expatriate Resources upon acquiring the WOL claims from Cominco was to test the down-dip extension of the Wolverine deposit (see also Bradshaw et al., and Piercey et al., this volume). The Wolverine deposit is open down-dip for 800 m along the WOL claim boundary. The first hole drilled on

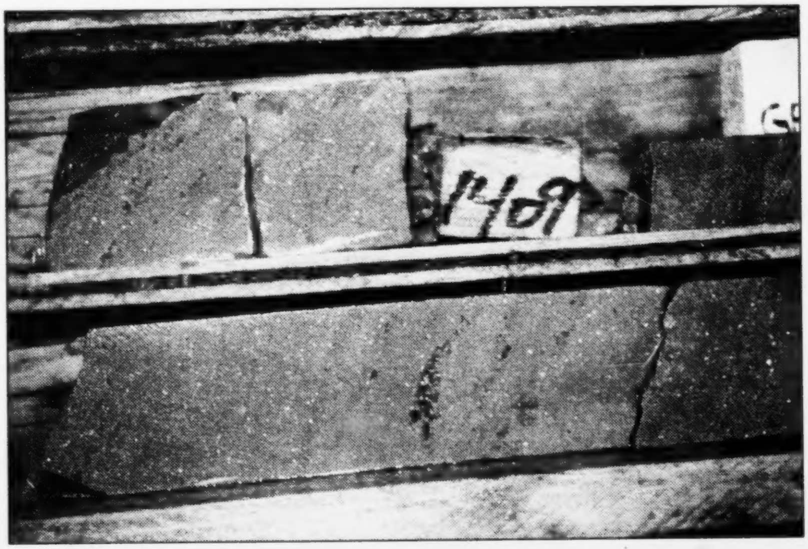


Figure 9. *Close-up of massive sulphide intersection from drill hole WW00-01 on the Wolverine project (NQ core). The hole intersected 7.4 m of 13.56% Zn, 1.16% Pb, 0.68% Cu, 152 g/t Ag and 0.59 g/t Au.*

the WOL claims, WW00-01, intersected a true thickness of 7.4 m of 13.56% Zn, 1.16% Pb, 0.68% Cu, 152 g/t Ag and 0.59 g/t Au (Fig. 9); hole WW00-01 is located approximately 100 m down dip from drill hole WV96-64. The second hole drilled on the WOL claims did not deviate as expected and intersected the Wolverine horizon approximately 300 m down dip from hole WW00-01. Hole WW00-02 intersected a weakly mineralized graphitic argillite overlain by a calcite-pyrite exhalite unit. Hole WW00-03 was drilled approximately 100 m northeast of hole WW00-01 and intersected a true thickness of 1.4 m of massive sulphide mineralization and 1.1 m of copper-rich stringer zone mineralization. The entire interval returned 2.5 m grading 8.33% Zn, 1.32% Pb, 1.55% Cu, 293 g/t Ag and 1.17 g/t Au. Additional drilling is required to fully test the down-dip potential of the Wolverine deposit on the WOL claims. Expatriate also conducted University of Toronto electromagnetic (UTEM) and magnetometer surveys in the area of the Kudz Ze Kayah deposit and Fault Creek zone to better define targets in that area.

Expatriate began compilation of the large amount of data acquired from Cominco and integrated it with existing data on their wholly owned claims, as well as data from the Expatriate/Atna joint venture. The database covering the Finlayson district will be used to prioritize the numerous targets within a large tract of land, which covers over 1700 km^2 of claims.

The **Goal/Net** property of Expatriate is located 6 km south of the GP4F deposit and is interpreted to occur at the same stratigraphic horizon. Four drill holes, totalling 500 m, were drilled (Fig. 10) in an area of strong multi-element soil geochemistry and induced polarization (IP) chargeability anomalies. Drilling intersected 0.73 m of semi-massive sulphides assaying 3.0% Zn, 1.85% Pb, 0.14% Cu, 63 g/t Ag and 0.2 g/t Au in hole GN00-02 within a quartz-porphyry rhyolite. Additional UTEM geophysical surveys were conducted, which identified a shallow, weak conductor. Follow-up drilling on the conductor included hole GN00-03, which failed to reach bedrock, and hole GN00-04, which intersected 0.3 m of semi-massive sulphides assaying 3.0% Zn, 0.7% Pb, 0.08% Cu and 9.4 g/t Ag. The mineralization is characterized by very low levels of selenium similar to the GP4F deposit. Additional drilling will be conducted in 2001 to test this new mineralized horizon.

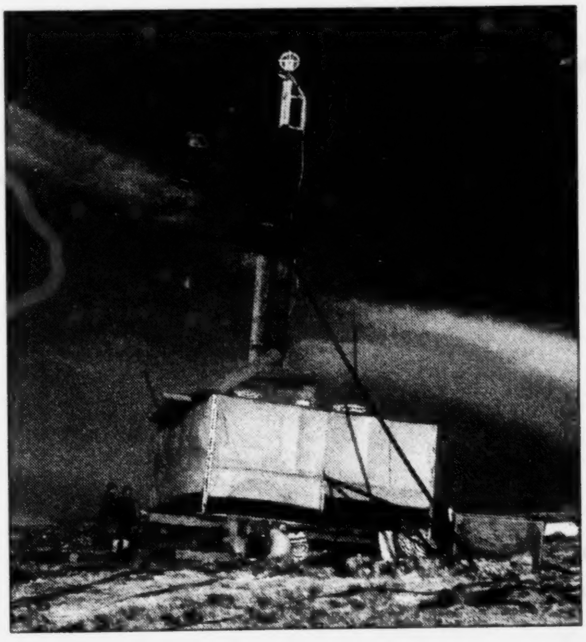


Figure 10. *Drilling on the Goal/Net property intersected semi-massive sulphide mineralization.*

Eagle Plains Resources Ltd. conducted a reconnaissance program in the northern portion of the Pelly Mountains

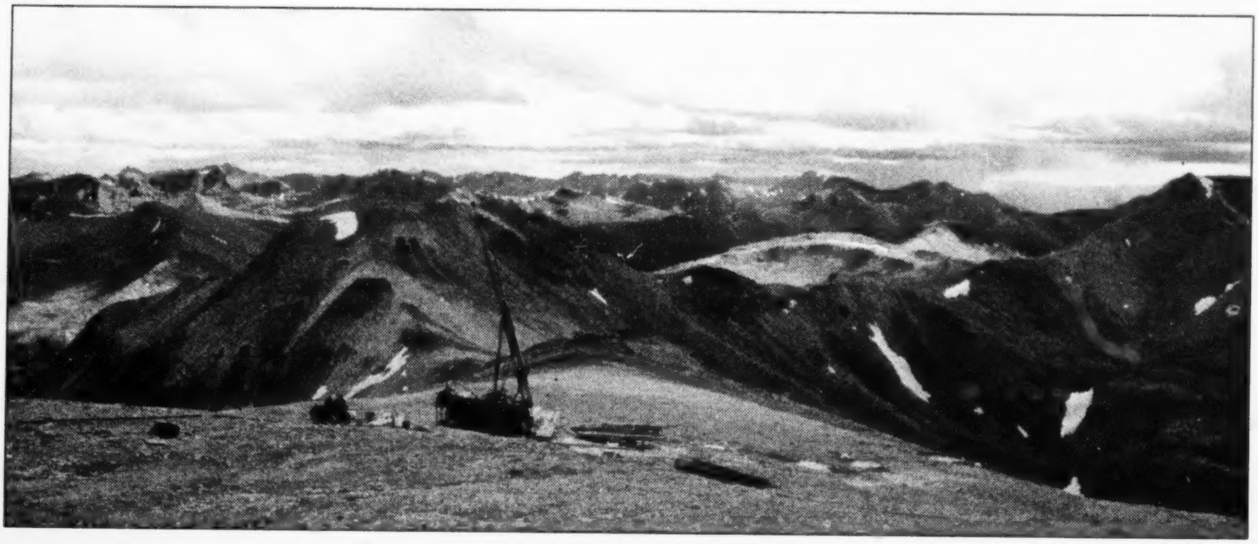


Figure 11. Eagle Plains Resources conducted helicopter-supported diamond drilling on the Fire property in the Pelly Mountains volcanic belt.

volcanic belt, a belt of Mississippian volcanic stratigraphy, which hosts numerous VMS showings including Atna Resources' Wolf deposit (4.1 Mt at 6.2% Zn, 1.8% Pb and 84 g/t Ag). Eagle Plains has been active in the belt since 1996 when they originally staked the **Fire** and **Ice** properties (Yukon MINFILE, 1997, 105F 071, 073). In addition to the reconnaissance program, Eagle Plains conducted geological mapping, soil geochemistry and prospecting, followed by a 6-hole, 730-m helicopter-supported drill program on the Fire (Fig. 11), Ice and **St. Cyr** properties (Yukon MINFILE, 1997, 105F 102). The drilling resulted in the discovery of a mineralized barite horizon on the Fire property, as well as on the Ice property, 7 km to the southwest. Four holes drilled from the same setup intersected the barite horizon on the Fire property with the best results obtained in DDH F00-02, with 15.1 m at 22.4 g/t Ag, 1529 ppm Pb, 6033 ppm Zn, and includes 3.3 m at 65.5 g/t Ag, 4930 ppm Pb and 2.15% Zn. A single hole was collared on the Ice property (Fig. 12), which intersected a thick-bedded barite-pyrite-tuff unit. The

Figure 12. Tim Termuende (right), President of Eagle Plains Resources and Bernie Kreft examine massive barite-sphalerite-galena mineralization in talus at the SB showing on the Ice property.

barite horizon averaged 8.9 g/t Ag, 5019 ppm Zn and 1659 ppm Pb over 48.4 m, including 1.3 m of 5.64% Zn, 0.17% Pb and 12.3 g/t Ag. Eagle Plains subsequently staked claims on regional targets identified from the reconnaissance program and prospective stratigraphy adjoining the Fire and Ice properties. Additional drilling is planned to follow up on this significant discovery in 2001.

Approximately 40 km to the northwest of the Fire and Ice properties, Tanana Exploration, a local private exploration company, conducted a program of geological mapping, prospecting, and hand- and blast-trenching on their **Fox** property (Yukon MINFILE, 1997, 105F 036). Trenching was conducted in the Ram zone, up slope from numerous large (up to several tonnes) float boulders of rusty weathering, white quartz-sulphide mineralization, containing bands and lenses of sphalerite and galena. Float in the area assays up to 11.5% Zn, 10.2% Pb and 78.9 g/t Ag. The trenching exposed an intensely oxidized and sericite-altered phyllite horizon over a 500-m strike length. Some trenches contained quartz-sulphide zones as lenses or replacement (?) zones. Trenching returned elevated Zn-Pb-Ag-Cu values, while select samples returned up to 9.7% Zn. Prospecting on Avalanche Ridge, 3.5 km northeast of the Ram zone, revealed float boulders of rusty-weathering, white quartz-sulphide mineralization similar to that from the Ram zone (Fig. 13). Float from Avalanche Ridge assayed up to 21.4% Zn, 4.4% Pb and 20.8 g/t Ag. Prospecting also located quartz-carbonate-sulphide veining at the contact of the phyllite and overlying chlorite schist. Float samples in the area returned up to 20.2 g/t Au, 569.7 g/t Ag, 17.5% Pb and 6.5% Zn.

Fairfield Minerals continued to explore the **Mor** property (NTS 105C/1) in the Teslin area of southern Yukon. The property is underlain by stratigraphy that has been correlated to the Nasina Assemblage of the Yukon-Tanana Terrane, which hosts VMS deposits in the Finlayson Lake district. During the 2000 exploration

Figure 13. *Ken Galambos (centre) of the Yukon Mining Incentive Program examines newly discovered massive sulphide mineralization in float at the Avalanche Ridge showing on the Fox property of Tanana Exploration.*

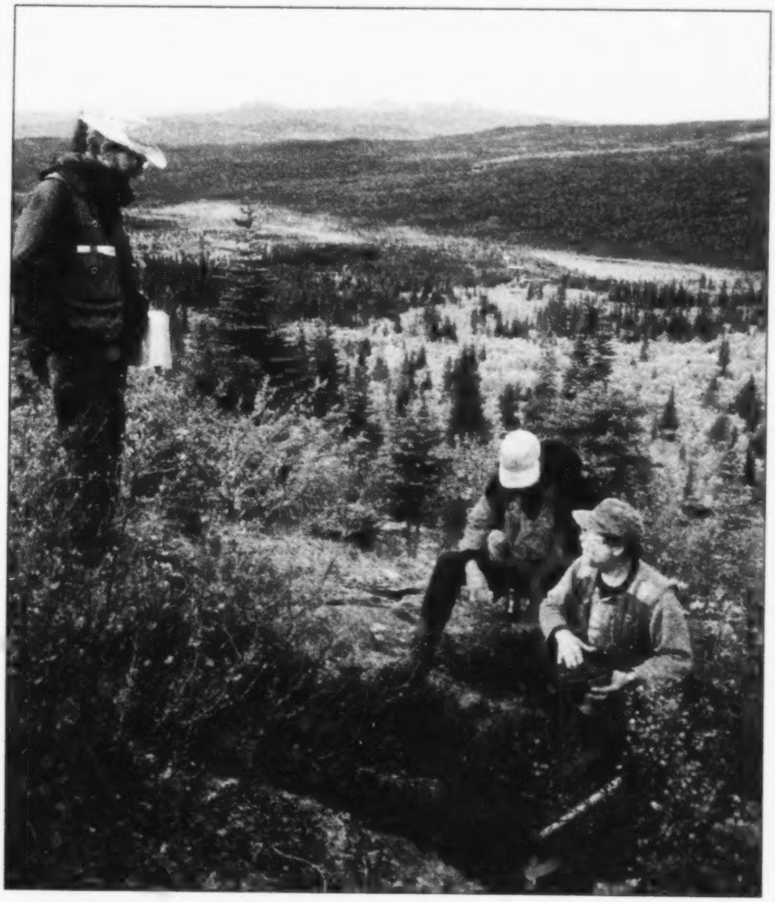


Figure 14. Ed Balon (right) and Wojtec Jakubowski (left) with Fairfield Minerals examine a pyrite-magnetite horizon hosted in chlorite schist on the Mor property with Maurice Colpron of the Yukon Geology Program (far left).

season, Fairfield conducted grid soil sampling, auger drill soil sampling, prospecting, as well as magnetic and VLF (very low frequency) ground geophysical surveys. The work confirmed, enhanced and extended the main anomaly trend (Cu-Pb-Zn-Ag ± Au ± Ba), which encompasses the discovery showing (Fig. 14). Grab samples from mineralized quartz-sericite schist/ rhyolite tuff at the discovery showing has returned assays of up to 8.91 g/t Au, 82.2 g/t Ag, 1.05% Cu, 5081 ppm Pb and 5515 ppm Zn. Current studies in the area by the Ancient Pacific Margin NATMAP (National Mapping Program) have advanced the geologic understanding of this portion of Yukon-Tanana Terrane and have highlighted the potential for future discoveries in the area (Colpron and Yukon-Tanana Working Group, this volume).

Atna Resources acquired a 66.7% interest in the **Marg** (Yukon MINFILE, 1997, 106D 009) property located near Mayo in central Yukon; Atna Resources Ltd.'s joint venture partner is Cameco Corporation. The property hosts a volcanogenic massive sulphide deposit with an indicated resource of 5.5 Mt grading 1.8% Cu, 4.6% Zn, 2.5% Pb, 62.7 g/t Ag and 0.98 g/t Au. The deposit is hosted within metasedimentary and metavolcanic rocks of the Devonian-Mississippian Earn Group and Mississippian Keno Hill Quartzite. These rocks form part of the Selwyn Basin, an off-shelf sequence that developed at the continental margin prior to Cordilleran deformation and accretion. Atna conducted a program of core re-logging, structural mapping and prospecting to re-assess the potential of the property. The program resulted in a re-interpretation of the geological setting of the deposit, which identified new areas of potential for additional resources. Subsequent prospecting discovered new mineralized areas. Atna is currently seeking a joint venture partner on the Marg property. For a description of the structure and stratigraphy of the Marg deposit, see Holbek et al. (this volume).

Copper Ridge Exploration acquired an option from Placer Dome Ltd. and U.S. Steel Group to purchase a 100% interest in the **Howards Pass** Zn-Pb-Ag sedimentary exhalative deposit (Yukon MINFILE, 1997, 105I 012). Subsequent to the Placer Agreement, Copper Ridge granted Billiton Metals Canada Inc. an option to obtain a 70% interest in the property. Billiton unfortunately withdrew for non-technical reasons from the project after their due-diligence review. The withdrawal of Billiton resulted in Copper Ridge not being able to make the initial payment to the vendors under the Placer Dome Agreement, and Copper Ridge was considering withdrawing from the project.

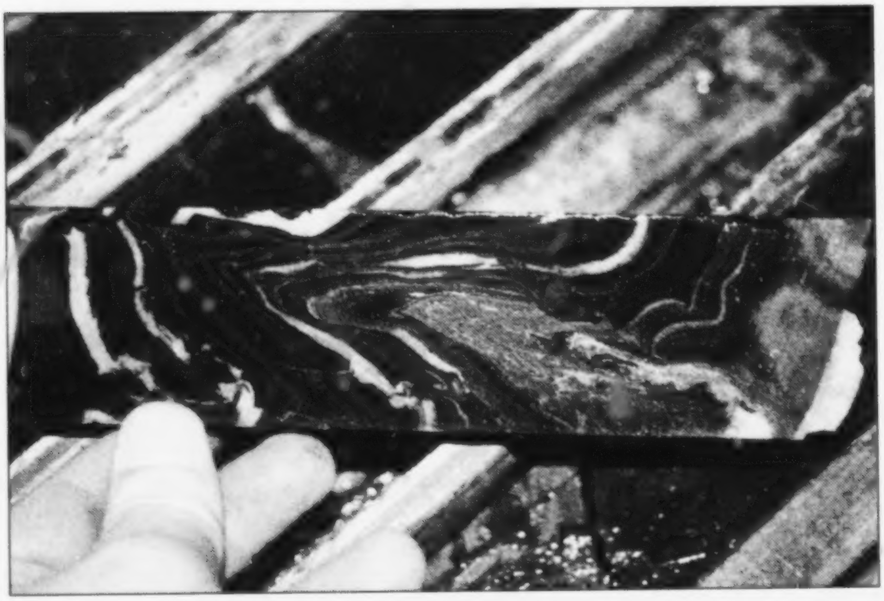


Figure 15. *Banded sphalerite-galena mineralization showing de-watering structures from Hole A-67 drilled in the Don Valley area at the Howards Pass project.*

The deposit hosts a resource calculated by Placer Dome of 110.5 Mt grading 5.4% Zn and 2.3% Pb. Howards Pass is located in the Selwyn Basin, a late Precambrian through Middle Devonian clastic and carbonate basin of off-shelf or deeper-water facies. The Selwyn Basin contains one of the world's largest concentrations of sediment-hosted stratiform zinc, lead deposits. Copper Ridge proposed examining the feasibility of the Howards Pass deposit by utilizing bulk mining methods, hydrometallurgy and gas turbine power. Hydrometallurgy has the potential to increase zinc recoveries and dramatically reduce the transportation costs associated with the project by producing zinc metal on-site, therefore eliminating the production of concentrates that need to be transported to a smelter. The availability of natural gas in southeastern Yukon from either the Kotaneelee gas field or from the proposed Alaska Highway pipeline, offers the option of producing gas turbine power as opposed to expensive on-site diesel generation.

Copper Ridge completed an eight-hole diamond-drilling program on the property to test two areas, the Don Valley (Fig. 15) and the Anniv Central, for near-surface open-pit potential. The three holes drilled in the Don Valley area all intersected significant mineralization, returning values up to 25.4 m of 4.34% Zn in Hole A-67, 14.5 m of 4.32% Zn in Hole A-69 and 23.7 m of 4.27% Zn in Hole A-71. Drilling in the Anniv Central area tested an overburden-covered area that had not been previously drill tested. The drilling defined the stratigraphy in the area with the final hole testing the complete mineralized section, which returned 19.6 m of 6.14% Zn and 1.99% Pb, including an 8.0 m section grading 10.56% Zn and 3.53% Pb.

Nordac Resources Ltd. conducted two short diamond-drilling programs on the **Quarterback** (QB; Yukon MINFILE, 1997, 105B 098) and **Blue Heaven** (Yukon MINFILE, 1997, 105B 020) properties in the Rancheria silver district in southern Yukon. Drilling was directed at zinc-lead mineralization in carbonate replacement zones. The QB drilling tested two zones: one, a mineralized fault zone, which extended into non-reactive schist and returned disappointing results, and the second, a replacement zone, where drilling revealed that the zone had a shallower

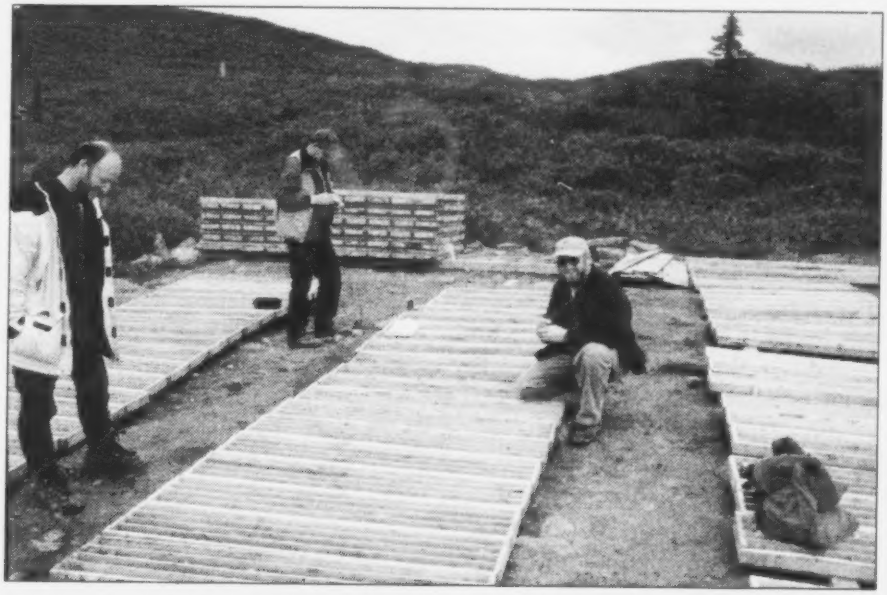


Figure 16. *Craig Hart (left) of the Yukon Geology Program examining core with geologists from Alexis Resources on the Canadian Creek property.*

than expected dip. This limits tonnage potential of the zone. The best hole in the replacement zone returned 39.9 g/t Ag, 0.73% Zn and 0.48% Pb over 9.88 m. On the Blue Heaven property, a single hole into a replacement zone adjacent to a high-grade vein fault revealed that the replacement style mineralization did not extend into the adjacent carbonate rocks. The hole returned 6.0 g/t Ag, 2.67% Zn and 0.10% Pb over 3.11 m.

Alexis Resources conducted a diamond-drilling program on the **Canadian Creek** (Yukon MINFILE, 1997, 115J 101) property optioned from Wildrose Resources. The Canadian Creek property is adjacent to the Casino deposit (531 Mt grading 0.26% Cu, 0.025% MoS_2, and 0.25 g/t Au) located in the Dawson Range approximately 150 km south of Dawson. Porphyry copper-gold-molybdenum and porphyry gold mineralization were targeted with a 12-hole reconnaissance style drill program (Fig. 16) on the large property. Hole CC-2000-01 was drilled on claims optioned from Great Basin Gold where drilling in 1994 in hole 94-319 returned 0.73 g/t Au over 44 m. Hole CC-2000-01 confirmed the previous result returning 50.5 m grading 0.71 g/t Au including 25.7 m of 1.04 g/t Au. The Creek zone, 7.5 km west of the Casino deposit, is a large geophysical target defined by a 2.4- by 2.0-km induced-polarization chargeability anomaly on the edge of a magnetic-high anomaly. Trenching in the Creek zone has exposed sub-crop of quartz-sericite-altered quartz diorite to monzonite from which composite sampling returned values of 0.72, 0.80 and 0.94 g/t Au. Drilling in and around the Creek zone returned values up to 11.7 m of 0.29% Cu in hole CC-2000-06, 3.0 m of 0.97 g/t Au, 0.12% Cu in CC-2000-11 and 3.0 m of 0.36 g/t Au, 0.20% Cu in hole CC-2000-12. A biotite-altered intrusive float boulder mineralized with malachite-chalcopyrite stockwork was discovered during the program, and contained 3.25% Cu with minor gold and molybdenum.

Prospector International conducted grid and reconnaissance soil sampling, prospecting and mapping on the **Coffee Creek** (Yukon MINFILE, 1997, 115J 050) and **Rude Creek** (Yukon MINFILE, 1997, 115J 022) properties located near the

Canadian Creek property in the Dawson Range of central Yukon. Grid soil sampling on the Coffee Creek property defined a 400- by 900-m, greater than 40-ppb-gold anomaly (up to 694 ppb Au) with elevated arsenic, antimony and mercury. The anomaly is underlain by quartz-mica schist near the northern contact of a mid-Cretaceous granitic intrusive. On the Rude Creek property a 150- by 550-m, greater than 38 ppb gold-in-soil anomaly (up to 1250 ppb Au) was defined. The anomaly has associated anomalous bismuth, silver and arsenic.

In the Whitehorse area, Kluane Drilling and partner Rob Hamel contracted Amerok Geosciences to conduct an induced polarization (IP) survey of the **HAT** claims (Yukon MINFILE, 1997, 105D 053) in the Whitehorse Copper Belt. The survey was conducted to expand an induced polarization (IP) chargeability anomaly identified from a survey conducted by Hudson Bay Mining and Smelting Co. Ltd. in the 1980s. Trenching in 1998 and 1999 on the claims exposed potassically altered granodiorite, which assayed up to 1.05% Cu, 180 ppb Au, 8.7 g/t Ag and 0.061% MoS_2. Two diamond drill holes were drilled in 2000 to test for porphyry-style mineralization at the margin of the IP anomaly. The holes intersected mainly sedimentary rocks and dykes or sills of granodiorite. The first hole intersected a section of high-grade, garnet-diopside-wollastinite skarn, mineralized with bornite and chalcopyrite, which assayed 4.99% Cu, 1.05 g/t Au and 40.3 g/t Ag over 10.55 m (Fig. 17). The drilling illustrates the potential for further discoveries of high-grade copper-gold skarn mineralization in the Whitehorse Copper Belt, which has produced over 10 million tonnes of ore with an average grade of 1.5% Cu, 0.55 g/t Au and 8.1 g/t Ag. The IP anomaly and porphyry potential on the HAT claims also remains to be fully tested.

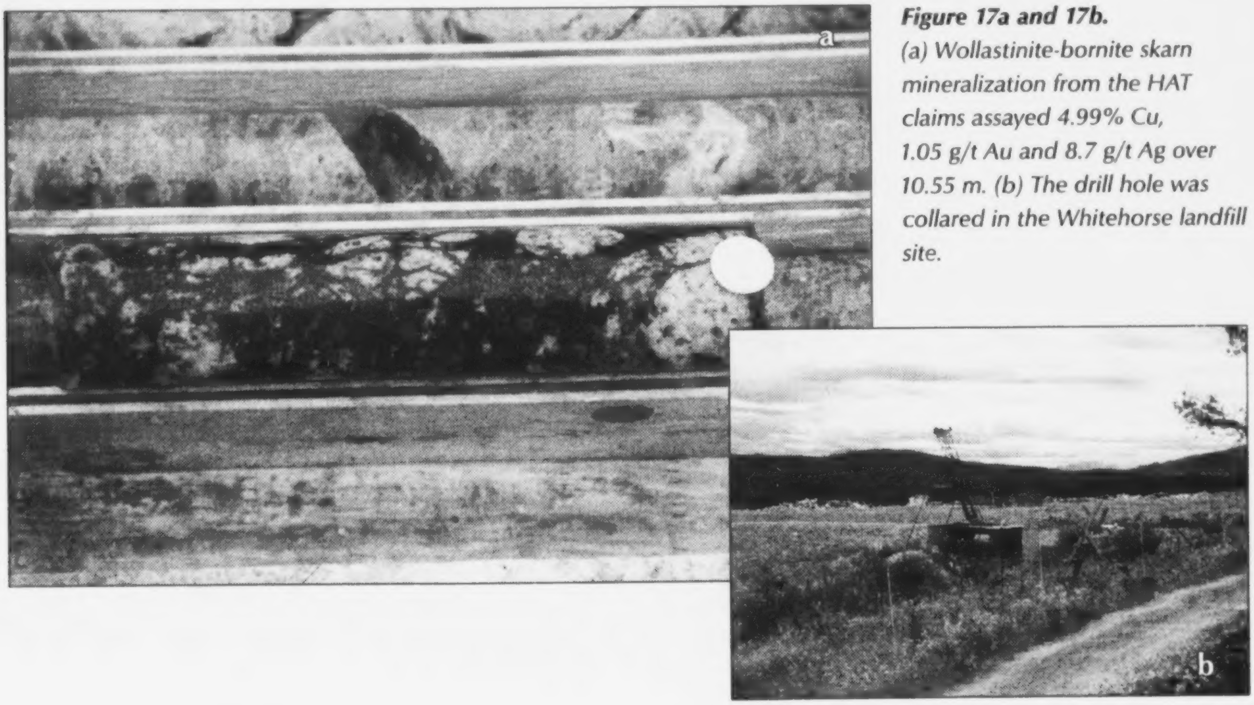


Figure 17a and 17b.
(a) Wollastinite-bornite skarn mineralization from the HAT claims assayed 4.99% Cu, 1.05 g/t Au and 8.7 g/t Ag over 10.55 m. (b) The drill hole was collared in the Whitehorse landfill site.

GOLD EXPLORATION

Gold exploration in 2000 was directed mainly at intrusive-related gold targets within the Tintina gold belt. The recognition of the multiple styles of deposit types in the belt and the potential of intrusive-related gold targets in several mid-Cretaceous plutonic suites has resulted in the Tintina gold belt encompassing a wide area of the Yukon. The projects conducted in 2000 were directed at several of the mid-Cretaceous plutonic suites and several small drilling programs returned significant results.

Canadian United Minerals, a private Yukon-based exploration company, conducted a small 350-m, eight-hole diamond-drilling program on the **Horn** property (NTS 116B/07) located within the boundaries of the proposed Tombstone Territorial Park. The claims cover part of a roof pendant of sedimentary rocks of Devonian to Jurassic age enclosed by quartz monzonite of the Tombstone pluton. Pyroxene and pyrrhotite skarns containing gold, silver, copper, lead, zinc, arsenic and bismuth are developed in Permian Takhandit Formation limestone lenses. The drilling was conducted to define a mineral reserve in the high-grade gold skarn exposed by trenching in 1999. Channel sampling in Trench 99-01 has returned values up to 58.9 and 85.44 g/t Au over widths of 5.94 and 4.45 m, respectively. Three fences of drill holes spaced 15 m apart were drilled beneath the exposure of pyrrhotite-chalcopyrite skarn in Trench 99-01. The drilling intersected skarn in all holes, with several intersections containing abundant visible gold (Fig. 18). The company has not yet released detailed information on the results of the program. Several targets on the property defined by mineralized float, Kubota trenching and detailed ground magnetic surveys remain to be tested by drilling.

Redstar Resources conducted a 9-hole, 1211-m diamond-drilling program on the **Clear Creek** property (Yukon MINFILE, 1997, 115P 012, 023) optioned from Newmont Exploration of Canada. Drilling (Fig. 19) was directed at the Bear Paw breccia zone, which was discovered through drilling late in 1999. The Bear Paw breccia is a quartz-breccia zone cutting metasedimentary and intrusive rocks

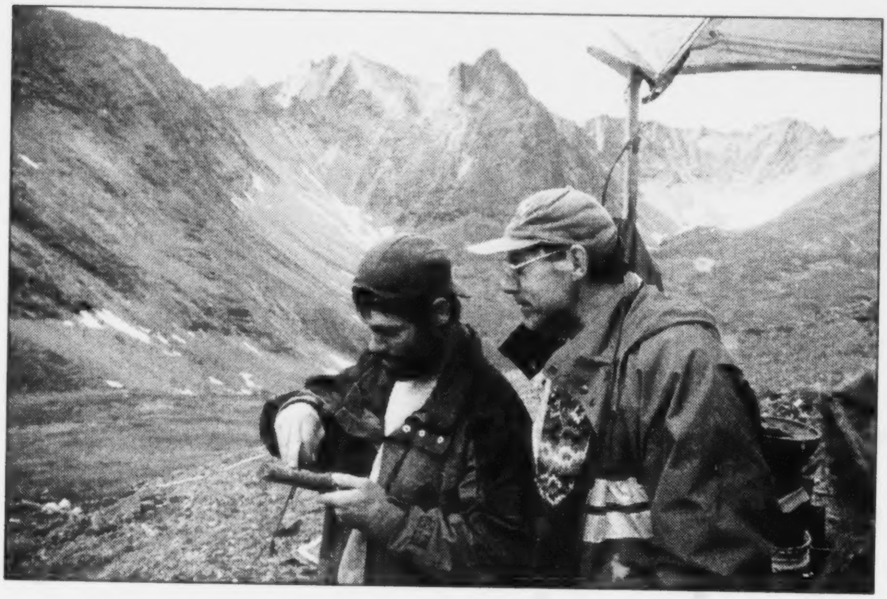


Figure 18. Shawn Ryan (left) of Canadian United Minerals and Dave Tenney, consulting geologist, point to visible gold in drill core from the Horn property.

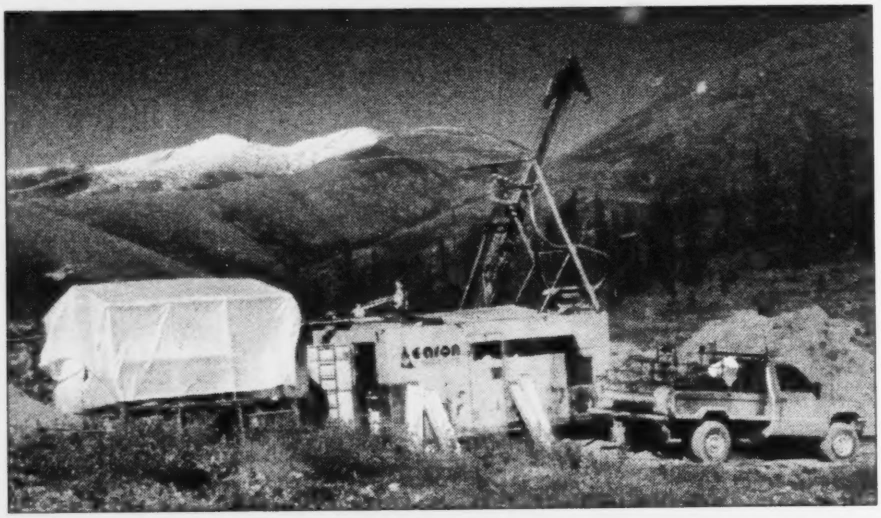


Figure 19. *Diamond drill on the Bear Paw breccia zone at the Clear Creek property.*

(Fig. 20). The zone is defined by a 1300- by 1100-m gold-arsenic-bismuth geochemical anomaly, which coincides with a magnetic-low geophysical anomaly. Drilling followed up on the discovery hole BP99-01, which intersected 26.7 m of 2.0 g/t Au. All of the holes drilled in 2000 intersected significant gold mineralization in quartz breccia. Two holes were drilled along an east-west section that includes the discovery hole BP99-01. Hole BP2000-03 was drilled 50 m from the discovery hole and returned 34.9 m of 2.0 g/t Au in quartz breccia; hole BP2000-10 was drilled 50 m from hole BP2000-03 and intersected 31.8 m of breccia grading 2.3 g/t Au. Interpretation of the drill results, utilizing recent structural interpretations (Stephens et al., 1999, Stephens and Weekes, this volume) suggest the mineralization is hosted by an easterly trending structure. Intersections peripheral to the main structure returned values up to 21.0 m grading 1.0 g/t gold in quartz breccia. Narrow intersections of calc-silicate style mineralization were also

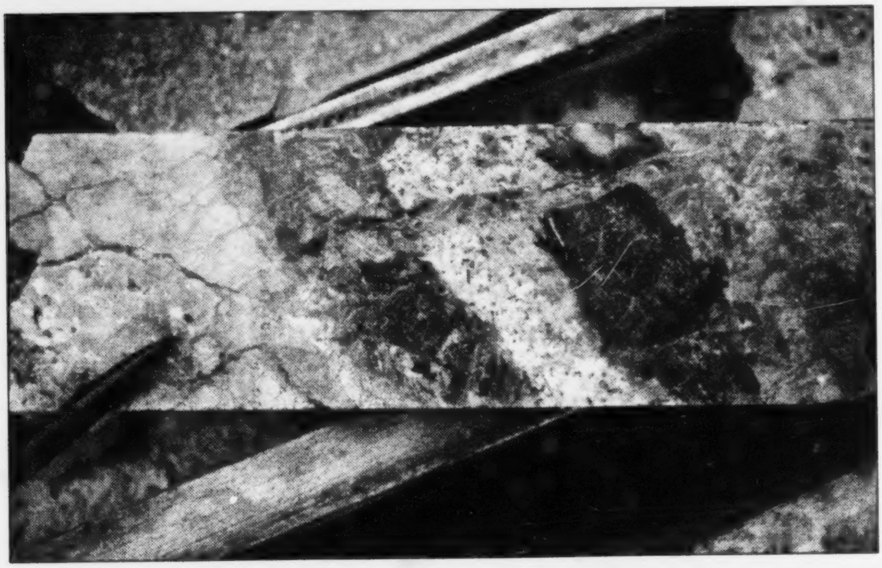


Figure 20. *Metasedimentary and intrusive clasts in quartz breccia from hole BP2000-03 on the Clear Creek property of Redstar Resources.*

intersected indicating additional styles of undiscovered mineralization are present in the area.

Newmont Exploration of Canada has optioned several contiguous properties in the Mayo area of central Yukon. The properties include the **Aurex** (Yukon MINFILE, 1997, 105M 060) optioned from Expatriate and YKR International Resources, Expatriate's **Sinister** property, and the **McQuesten** (Yukon MINFILE, 1997, 105M 029) optioned from NovaGold and Eagle Plains Resources. Newmont conducted airborne geophysical surveys, Bombardier-mounted auger drilling, mapping and prospecting over the properties, followed by a 5-hole, 883-m diamond-drilling program on the McQuesten property. The McQuesten property is underlain by Neoproterozoic to Lower Cambrian Hyland Group metasedimentary rocks in the immediate hanging wall of the regional-scale Robert Service Thrust. The Hyland Group rocks are variably calcareous. Previous drilling and trenching programs indicated a large mineralized system, consisting of disseminated and massive pyrrhotite, pyrite and arsenopyrite in quartz-sericite and calc-silicate alteration zones. The mineralized zone is contained within a structural corridor that is over 3 km in length. The five holes drilled by Newmont tested a 1.2 km section of the structural corridor and all five holes intersected significant mineralization. Results include: Hole MQ-00-01 intersecting 2.5 m of 3.2 g/t Au, MQ-00-02 intersecting 13.5 m of 0.7 g/t Au, MQ-00-03 intersecting 3.0 m of 2.0 g/t Au and 3.0 m of 3.0 g/t Au, MQ-00-04 intersecting 11.5 m of 1.5 g/t Au and 36.6 m of 1.4 g/t Au, and hole MQ-00-05 intersecting 13.9 m of 1.27 g/t Au. The property is adjacent to the Keno Hill silver-lead-zinc district, which has produced over 62 billion grams (200 million ounces) of silver. The property is accessed via the all-weather Silver Trail highway and is bisected by a hydroelectric power transmission line.

Newmont Exploration of Canada conducted a detailed airborne magnetic survey, and soil sampling followed by diamond drilling on the **Longline** property (Yukon MINFILE, 1997, 105N 024) of Barramundi Gold, located in west-central Yukon. The property is underlain by granodiorite of the Klotassin Batholith, which is host to

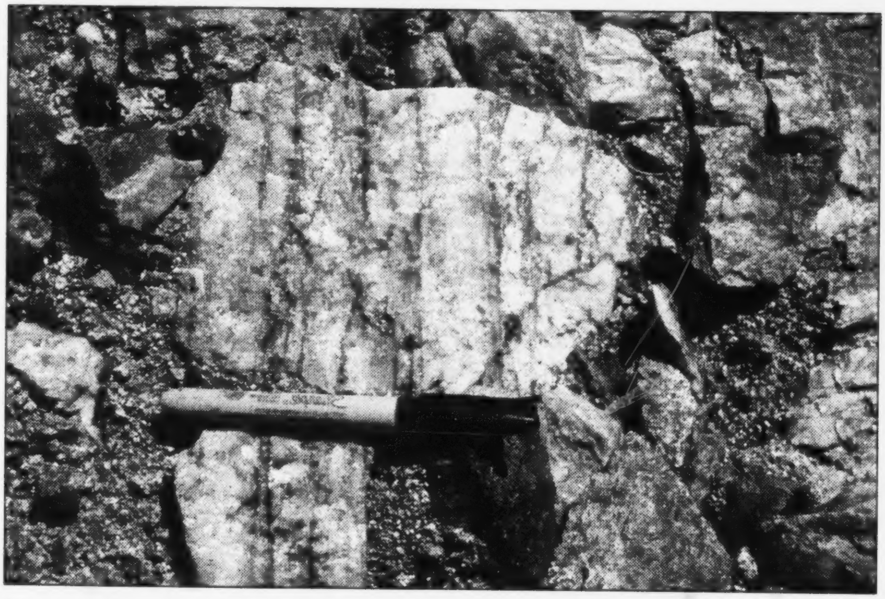


Figure 21. *The V-1 vein, pictured here, is one of several high-grade quartz-sulphide vein occurrences on the Longline property of Barramundi Gold.*

several high-grade quartz-sulphide vein occurrences (Fig. 21). Newmont drilled six holes, totalling 1750 m, one to test the down-dip extension of the high-grade V3 gold vein, and the remaining five testing the 141 zone, a large arsenic ± gold, silver, bismuth, antimony soil anomaly. The down-dip hole on the V3 vein intersected two veins containing visible gold. The uppermost vein assayed 2.21 g/t Au over 0.20 m, while the second vein, located 15 m deeper in the hole, intersected 5.36 g/t Au over 0.31 m. The holes in the 141 zone tested structural zones interpreted from the airborne magnetic survey with coincident anomalous soil geochemistry. The drilling intersected zones of quartz-sericite-carbonate alteration as haloes around arsenic-lead-copper-bismuth-bearing sulphide veins. The best intersections from drilling was in hole LL-00-06, which assayed 0.64 g/t Au and 936 ppm Bi over 0.20 m and a second zone of 1.08 g/t Au over 0.20 m. Newmont also flew a detailed airborne magnetic survey over the **Moosehorn** property, optioned from Troymin Resources, adjacent to the Longline property.

Teck Exploration performed a program of geological mapping, prospecting, soil sampling and excavator trenching on the **Ten** property (Yukon MINFILE, 1997, 115N 110). The bulk of the trenching was performed on the Jual zone, an area of quartz veining hosted in a Cretaceous quartz monzonite intrusive (Fig. 22). Phelps Dodge conducted soil sampling, mapping and excavator trenching on the **Flume** property, which is contiguous with Teck's TEN claims. Their trenching was directed at areas of anomalous geochemistry in Yukon-Tanana Terrane metamorphic rocks peripheral to the quartz monzonite intrusive. No results were released from either program.

In the Dawson area, Nordac Resources conducted exploration on the **Eureka**, **Armenius** (Yukon MINFILE, 1997, 115N 057) and **Track** (Yukon MINFILE, 1997, 116C 137) properties, which are part of the Eureka joint venture with Expatriate Resources. Grid soil sampling, mapping, prospecting and rock sampling was conducted on the Eureka and adjoining Armenius properties. Three zones have been identified within a north-trending corridor of gold-in-soil anomalies. The three zones are characterized by crackle and milled breccia in float. Trenching in the

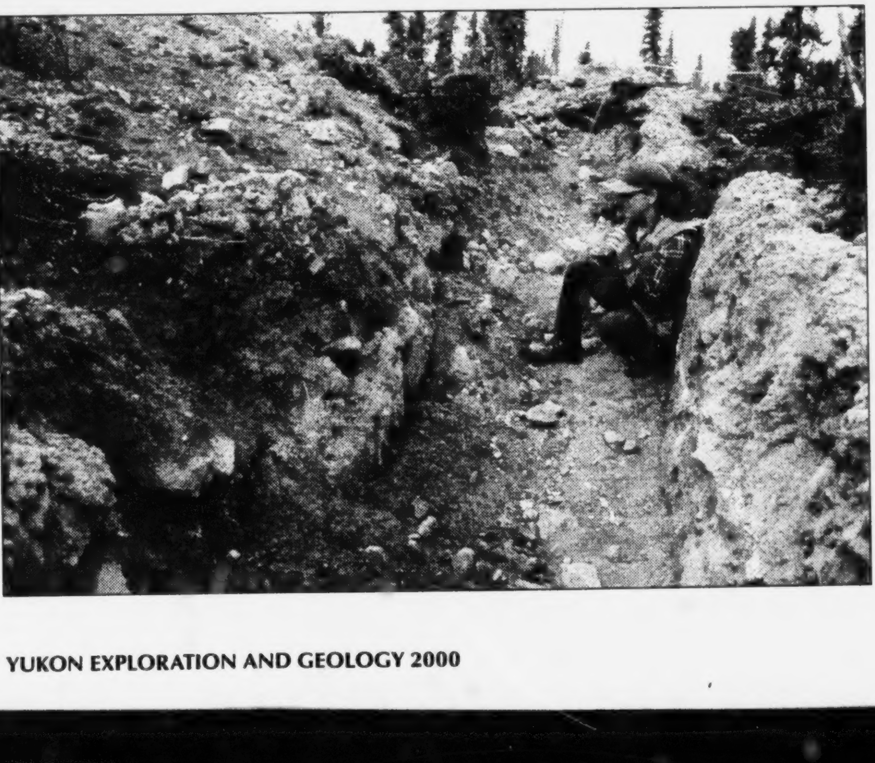


Figure 22. *Jean Pautler, formerly with Teck Exploration examines mineralization in the Jual zone on the Ten property.*

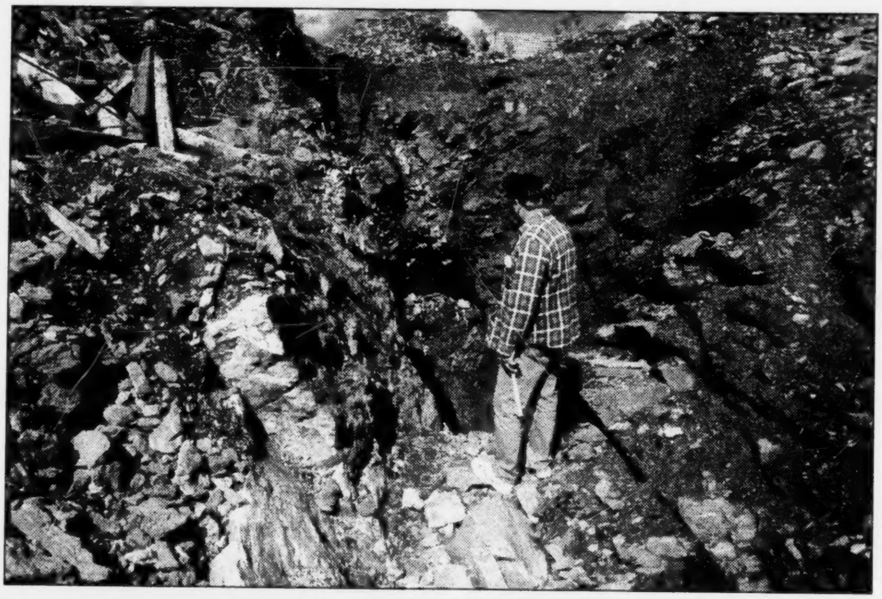


Figure 23. *Herman Liedtke examines the Mitchell shaft excavated in 1911 and exposed by trenching in 2000.*

headwaters of Eureka Creek has exposed a northeast-trending breccia zone, which assayed 0.33 g/t Au over 6.5 m. Composite float samples from the zone have returned values of 1.85 and 1.40 g/t Au. Gold values up to 14.42 g/t Au in float were obtained from the Allen showing, and at the Childs showing, float samples ranged from 0.46 to 3.97 g/t Au.

Klondike Source Limited, a private Australian company, conducted a program of Landsat and air-photo interpretation, structural mapping, prospecting and a Mobile Metal Ion (MMI) soil sampling survey on the **Hunker** property in the Dawson area. The company is re-interpreting the geology and structural setting of the area underlying the bulk of the Klondike Gold Fields.

Elsewhere in the Dawson area, JAE Resources, a private Yukon-based company, conducted trenching and sampling on the **Mitchell** property (Yukon MINFILE, 1997, 115O 068) near the head of Hunker Creek. The trenching was directed at the extension of the Mitchell vein, a mesothermal quartz-sulphide vein (Fig. 23), a new area of quartz veinlets exposed by trenching near the Hunker summit, and a multi-element soil geochemical anomaly.

International Kodiak Resources continued to explore their extensive **Oki Doki** property (Yukon MINFILE, 1997, 116B 013, 033) that adjoins the Brewery Creek mine. Two main areas were targeted in the current program. Area 5 is an intrusive-hosted gold target east of the mine (Fig. 24). A previously unmapped Cretaceous intrusion is coincident with a 600- by 800-m soil

Figure 24. *Marco Vanwermeskerken (left) and Bart Jaworski (right) with International Kodiak Resources examine intrusive-hosted mineralization in Area 5 on the Oki-Doki property. The Brewery Creek mine is just visible in the background.*

anomaly with up to 564 ppb Au, 98 ppm Bi and 6 ppm Te. Kodiak conducted additional mapping, sampling and helicopter-supported Kubota trenching in Area 5. Area 3 is just to the north of the Brewery Creek mine. Excavator and Kubota trenching, and additional soil sampling and mapping were performed on areas of anomalous silver-vanadium-zinc-nickel soil geochemistry in Devonian-Mississippian Road River shale. No results have been released from the current program.

In southeastern Yukon, NovaGold Resources conducted a 4-hole, 772-m diamond-drill program on the **Sun/Sprogge** (Yukon MINFILE, 1997, 105H 034) property. Several areas of mineralization exist on the property including skarn, high-grade arsenopyrite veins and disseminated mineralization in quartz-pebble conglomerate and sandstone of the Neoproterozoic to Lower Cambrian Hyland Group. The drilling tested an area of anomalous gold identified by previous contour and limited grid soil sampling (Fig. 25). The area is underlain by argillically altered quartz-pebble conglomerate and sandstone with interbedded phyllite. Silicification, quartz veining, quartz-arsenopyrite veining, limonite, and finely disseminated sulphides characterize the area. The drilling intersected wide zones of argillic and sericitic alteration, quartz veining, limonitic fractures and disseminated sulphides (mainly pyrrhotite and pyrite). No results were released from the program.

Athlone Resources conducted a small program of soil sampling, mapping and prospecting on the adjacent **HY** claims optioned from Phelps Dodge Resources.

Omni Resources and Trumpeter Yukon Gold amalgamated to form Tagish Lake Gold Corporation. The company holds a large number of claims in the Wheaton River gold district south of Whitehorse that hosts three known gold-silver deposits: **Skukum Creek** (Yukon MINFILE, 1997, 105D 022), **Mt. Skukum** (Yukon MINFILE, 1997, 105D 158) and the **Goddell** (Yukon MINFILE, 1997, 105D 025). In 2000, the company hired CME consultants to compile the on-site exploration data, locate diamond drill core and drill sites, and conduct assessment work on the claims. The company also added the historic **Charleston** vein (Yukon MINFILE, 1997,

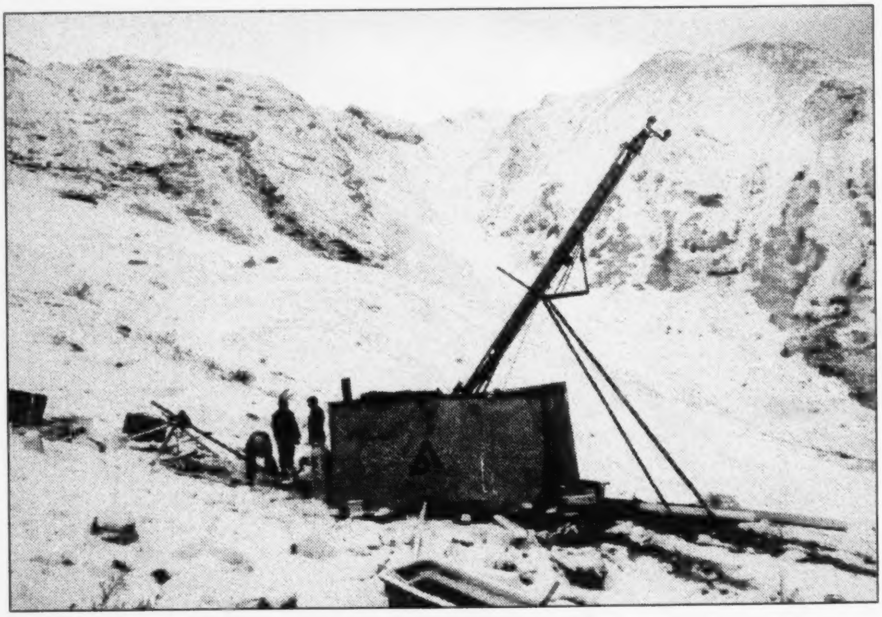
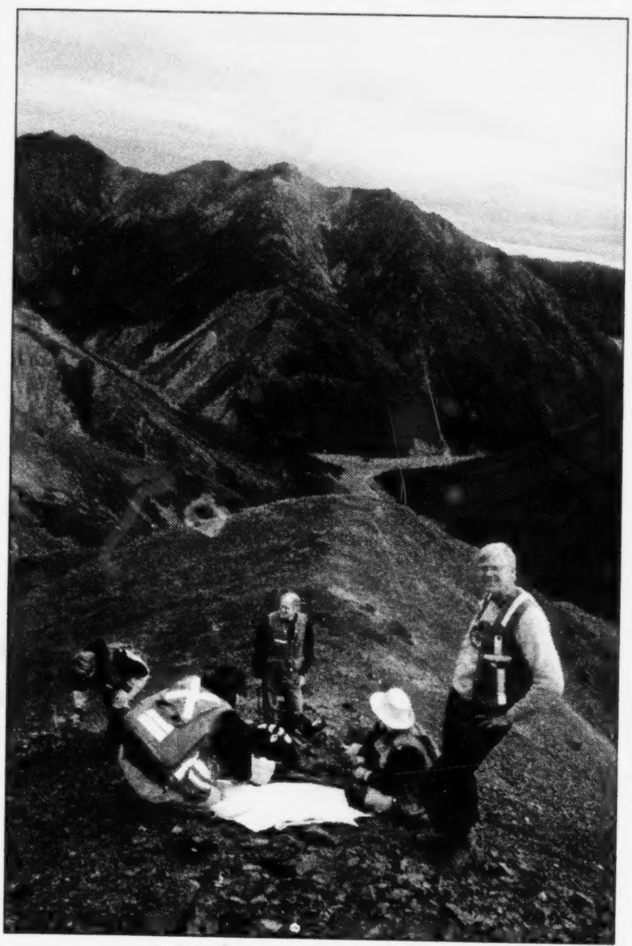


Figure 25. *Late season drilling on the Sun/Sprogge property of NovaGold Resources.*

105D 020) to their claim holdings in the region. Grab samples from the Charleston assayed up to 18.6 g/t Au. In 2001, the company intends to concentrate their efforts on upgrading and expanding the mineral resource in the Skukum Creek deposit.

Al Carlos conducted a geochemical survey utilizing the enzyme-leach technique on his **Grew Creek** (Yukon MINFILE, 1997, 105K 009) property. Carlos collected 558 samples on a 100- by 25-m-spaced cut grid over an area approximately 1 km east of the Grew Creek deposit. Grew Creek is an epithermal gold deposit adjacent to the Robert Campbell Highway, located midway between Faro and Ross River in central Yukon. The deposit hosts a drill-indicated geological resource of 773,012 tonnes grading 8.9 g/t Au and 33.6 g/t Ag (Christie, 1992). The enzyme-leach survey was directed at refining targets in a till-covered area that had produced spotty anomalies through conventional geochemical surveys. Anomalies were also indentified here through previous airborne electromagnetic and very low frequency (VLF) surveys. Five anomalous areas were identified during the survey, four along a west-northwest-trending structure supported by a ground-VLF survey conducted this summer. One of the four anomalies is associated with bismuth, an element not usually detected by enzyme-leach surveys. An interpretation of the survey suggests the presence of a buried rhyolite dome or unexposed Cretaceous intrusive. The fifth anomaly was identified to the south of the structural trend adjacent to an outcrop of silicified Tertiary sedimentary rock, which returned assays up to 2110 ppb Au. Mr. Carlos is seeking joint venture partners for the property.

Figure 26. *Santoy Resources geologists, Vice-president, Exploration, Ron Nichols (background) and Paul Wodjak (foreground) of the British Columbia Geological Survey examine mineralization on the Klu property.*



PLATINUM GROUP EXPLORATION

The recent increase in the value of platinum group metals (PGM) has captured the attention of exploration companies worldwide. Yukon experienced an increase in exploration for platinum group metals, however all the programs that were conducted in 2000 were grassroots in nature with the exception of Santoy Resources' work on the Klu property. Most programs were conducted in Triassic intrusive complexes in western Yukon within the 'Kluane mafic-ultramafic belt', which has long been recognized as having high PGM potential. The belt is described in detail by Hulbert (1997). The Yukon has high potential to host PGM deposits in several different geological settings.

Santoy Resources Ltd. optioned the **KLU** (Yukon MINFILE, 1997, 115G 003) claims in the Kluane mafic-ultramafic belt from Inco Ltd. The property covers an 18-km section of the belt, which contains six mafic-ultramafic intrusions (Fig. 26). They intrude Hasen Creek sedimentary rocks in several places at virtually the same stratigraphic position, which suggest the bodies may be one intrusion represented in fault-repeated sections of the stratigraphy. The most significant occurrence on the claims is a

Figure 27. *Adam Travis (foreground) with Santoy Resources examines the Sweet Sixteen showing hand trench on the Klu property.*

discovery made by Inco in 1994, which consists of small chalcopyrite-pyrrhotite lenses in sedimentary rocks at the base of the Spy sill. These lenses assay up to 2.6% Ni, 10.4% Cu, 0.09% Co, 75.8 g/t Pt, 7.9 g/t Pd and 7.0 g/t Au at the Spy showing. Santoy conducted a program of geological mapping, prospecting, trenching and soil sampling aimed at testing for widespread disseminated mineralization along the contact of the Spy sill with underlying sedimentary rocks. The program was successful in identifying disseminated mineralization over a minimum strike length of 950 m to the northwest of the Spy showing. Chip sampling returned values up to 0.45% Cu, 0.16% Ni, 7.07 g/t Pt, 1.34 g/t Pd and 0.69 g/t Au over 1.0 m at the Spy occurrence, and 0.12% Cu, 0.04% Ni, 1.85 g/t Pt, 1.55 g/t Pd and 1.07 g/t Au over 1.2 m at the Sweet Sixteen (Fig. 27) occurrence. Grab samples within the Spy sill, away from the contact zone, returned values up to 1.91 g/t Pt, 0.87 g/t Pd and 0.51 g/t Au suggesting the potential for additional mineralized horizons within the sill. Significant mineralization was also discovered on other areas of the property. Santoy is compiling the extensive Inco database on the property, which includes high-resolution aeromagnetic and electromagnetic surveys, limited University of Toronto electromagnetic ground (UTEM) surveys and geochemical surveys. Santoy intends to test the favourable stratigraphic interval with drilling in 2001.

Nordac Resources Ltd. conducted prospecting, soil sampling and hand trenching at the **Burwash** property (Yukon MINFILE, 1997, 115G 100) located within the Kluane mafic-ultramafic belt. Anomalous Pt-Pd-Ni-Cu from soil sampling outlined a 1000-m-long, 200- to 500-m-wide zone, which corresponds to a mafic-ultramafic dyke complex. Chip sampling from the margin of a 50-m-wide pyoxenite dyke within the zone returned a weighted average of 0.57 g/t Pt, 0.32 g/t Pd, 0.16 g/t Au, 0.22% Ni and 0.46% Cu over 7.0 m.

Auterra Ventures Inc. conducted a small program of geological mapping, prospecting and trenching on the **AR** claims (Yukon MINFILE, 1997, 115G 026) located in Arch Creek within the Kluane mafic-ultramafic belt. The property is located 5 km northwest of the Wellgreen deposit (Yukon MINFILE, 1997, 115G 024).

ACKNOWLEDGEMENTS

This report is based on public information gathered from a variety of sources. It also includes information provided by companies through press releases, property summaries provided to the department by companies and from property visits conducted in the 2000 field season. The cooperation of companies in providing information and their hospitality during field tours are gratefully acknowledged. Editing by Diane Emond and Leyla Weston is appreciated.

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APPENDIX 1: 2000 EXPLORATION PROJECTS

BS - Bulk Sample
D - Development
DD - Diamond Drilling
ES - Environmental Studies
F - Feasibility
G - Geology
GC - Geochemistry
GP - Geophysics
M - Mining
PD - Percussion Drilling
PF - Prefeasibility
R - Reconnaissance
T - Trenching
U/GD - Underground Development

PROPERTY	COMPANY	MINING DISTRICT	MINFILE # or (1:50 000 NTS)	WORK TYPE	COMMODITY
AR	Auterra Ventures Inc.	Whitehorse	115G-026	G,GC,T	PGE-Cu-Ni
Armenius	Expatriate/Nordac	Dawson	115N-057	G,GC,T	Au
Aurex	Expatriate/YKR	Mayo	105M-060	G,GC	Au
Blue Heaven	Nordac Resources	Watson Lake	105B-020	G,GC, DD	Ag-Pb-Zn-Cu
Brewery Creek	Viceroy Resources	Dawson	116B-160	M	Au
Caribou Creek/Mor	Brett/Fairfield Minerals	Watson Lake	(105C/1,5)	G,GC	Pb-Zn-Ag-Cu
Canadian Creek	Alexis/Wildrose Resources	Whitehorse	115J-036	G, DD	Cu-Au
Clear Creek	Redstar/Newmont	Mayo	115P-012,013	G, GC, DD	Au
Coffee Creek	Prospector International	Whitehorse	115J-050	G,GC	Au-Cu
St. Cyr	Eagle Plains Resources	Watson Lake	105F-102	G,GC,DD	Pb-Zn-Ag
Eureka	Expatriate/Nordac	Dawson	115N-057	G,GC,T	Au
Fire/Ice	Eagle Plains Resources	Watson Lake	105F-071,073	G,GC,DD	Pb-Zn-Ag
Fox	Tanana Exploration	Watson Lake	105F-036	G,GC,T	Cu-Pb-Zn-Au
Goal-Net	Expatriate Resources	Watson Lake	(105G/7,8)	G,GC,DD	Pb-Zn-Cu-Ag-Au
Grew Creek	Al Carlos	Whitehorse	105K-009	G,GC	Au-Ag
HAT	Coyne & Sons	Whitehorse	105D-053	G,GP,DD	Cu-Au-Ag
Horn	Canadian United Minerals	Dawson	(116B/7)	G,DD	Au-Cu
Howards Pass	Copper Ridge Exploration	Watson Lake	105I-012	G,GC,DD	Zn-Pb-Ag
Hunker	Klondike Source/ Barramundi	Dawson	(115NO/14,15)	G,GC	Au
Hy	Athlone Resources	Watson Lake	(105H/15)	G,GC	Au
Keno Hill	United Keno Hill	Mayo	105M-001	D	Ag-Pb-Zn
Klu	Santoy Resources	Whitehorse	115G-003	G,GC,T	PGE-Cu-Ni
Kudz Ze Kayah	Expatriate Resources	Watson Lake	105G-117	GP	Pb-Zn-Cu-Ag-Au
Livingstone	Larry Carlyle/Max Fuestner	Whitehorse	105E-001,042,049,054	G,GC,T	Au-Ag
Longline	Barramundi Gold Ltd./Newmont	Whitehorse	115N-024	G,GC,GP,DD	Au
McQuesten	Newmont/Novagold/Eagle Plains Resources	Mayo	105M-029	G,GC,DD	Au
May	Eagle Plains Resources	Mayo	115P-056	G,GC	Au
Marg	Atna Resources	Mayo	106D-009	G,GC	Pb-Zn-Cu-Ag-Au
Minto	Minto Resources	Whitehorse	115I-021,022	D	Cu-Ag-Au
Mitchell	JAE Resources	Dawson	115O-068	T	Au
Moosehorn	Newmont/Troymin	Whitehorse	115N-024	GP	Au
Nug	Eagle Plains Resources	Mayo	105O-048	G,GC	Au
Oki-Doki	International Kodiak	Dawson	(116B/1,A/4)	G,GC,T,GP	Au
P7P	Pacific Ridge Exploration	Dawson	115O-015	G	PGE-Cu-Ni

Appendix 1: continued

BS - Bulk Sample
D - Development
DD - Diamond Drilling
ES - Environmental Studies
F - Feasibility
G - Geology
GC - Geochemistry
GP - Geophysics
M - Mining
PD - Percussion Drilling
PF - Prefeasibility
R - Reconnaissance
T - Trenching
U/GD - Underground Development

PROPERTY	COMPANY	MINING DISTRICT	MINFILE # or (1:50 000 NTS)	WORK TYPE	COMMODITY
Quarterback	Nordac Resources	Whitehorse	105B-098	G,DD	Pb-Zn-Ag
Revenue	ATAC/YKR International	Whitehorse	115I-042	G	Cu-Au-Ag-WO$_3$-MoS$_2$
Rude Creek	Prospector International	Whitehorse	115J-022	G	Au-Cu
Skukum	Tagish Lake Gold	Whitehorse	105D-022,025,158	G	Au-Ag
Sun/Sprogge	NovaGold/Kennecott	Watson Lake	105H-034	G,DD	Au
Swan	Prospector International	Mayo	105O-024	G	Au
Track	Expatriate/Nordac	Dawson	116C-137	G,GC	Au
Wash	Nordac Resources	Whitehorse	115G-100	G,GC,T	Ni-Cu-Au-PGE
Wolverine	Expatriate/Atna Resources	Watson Lake	105G-073	G,GC,DD	Pb-Zn-Cu-Ag-Au

APPENDIX 2: 2000 DRILLING STATISTICS

PROPERTY	COMPANY	DIAMOND DRILL	
		METRES	# HOLES
Blue Heaven	Nordac Resources	90	1
Canadian Creek	Alexis Resources Ltd.	2066	12
Clear Creek	Redstar Resouces/Newmont	1211	9
Fire	Eagle Plains Resources	509	5
Goal/Net	Expatriate Resources	500	3
Horn	Canadian United Minerals	350	8
Howards Pass	Copper Ridge Exploration	717	8
Ice	Eagle Plains Resources	107	1
Longline	Newmont/Barramundi	1753.5	6
McQuesten	Newmont/Nova Gold/Eagle Plains Resources	883	5
Quaterback	Nordac Resources	273	3
St. Cyr	Eagle Plains Resources	105	1
Sun/Sprogge	Nova Gold/Kennecott	772	4
Whitehorse Copper	Coyne and Sons	357	2
Wolverine	Expatriate/Atna	3000	10
TOTAL		**12,693.5**	

YUKON PLACER MINING OVERVIEW, 2000

William LeBarge[1]
Yukon Geology Program

LeBarge, W., 2001. Yukon Placer Mining Overview. *In:* Yukon Exploration and Geology 2000, D.S. Emond and L.H. Weston (eds.), Exploration and Geological Services Division, Yukon, Indian and Northern Affairs Canada, p. 29-30.

Placer mining in the Yukon continued to be an important industry in 2000 despite low precious metal prices and steadily declining mineral exploration activity. A total of 140 mines operated, with approximately 450 people directly employed in the industry. This represents an 18% decrease in the number of mines from 1999. Still, many jobs in the service and hospitality industries are annually generated due to seasonal placer mining activity, especially in the Dawson and Mayo areas. The majority of active mining operations were in the Dawson Mining District, followed by the Whitehorse and Mayo Mining districts.

For 2000, over 85% of the Yukon's placer gold was produced in the Dawson district, which includes the unglaciated drainages of Klondike River, Indian River, west Yukon (Fortymile, Sixtymile, Moosehorn) and lower Stewart River. The remaining gold came from glaciated regions including Clear Creek, Mayo, Dawson Range, Kluane and Livingstone.

Placer gold production in 2000 totalled 76,507 crude ounces (2,379,635 g), compared to 87,680 crude ounces (2,727,155 g) for 1999, which represents a 15% decrease. The total dollar value of Yukon placer gold also dropped in 2000, down to $C 25.4 million from the $C 29.7 million generated in 1999. The 2000 mining season was the first time operators were required to have Mining Land Use licenses on their claims, in addition to water licenses. Along with the continuing low price of gold and unexpectedly high fuel prices, this made for challenging economic conditions for the Yukon's placer mining industry.

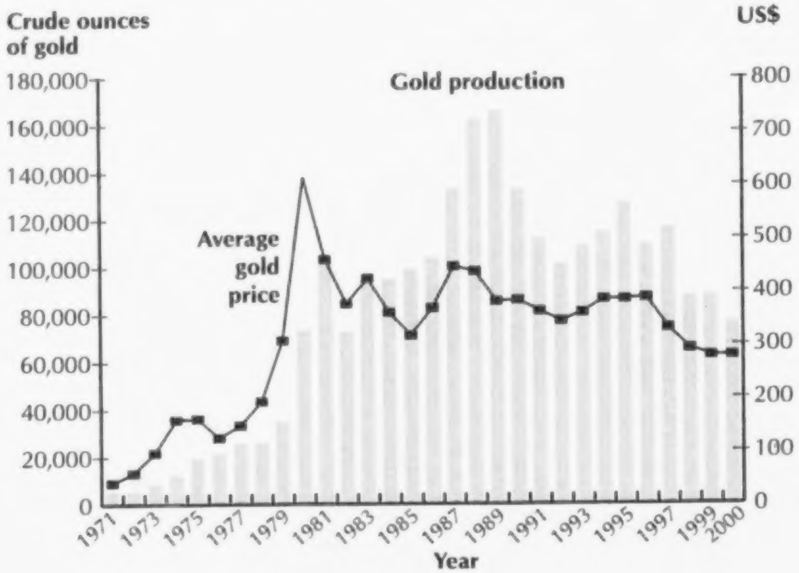

Figure 1. *Yearly gold production figures and average US gold price, 1971-2000, for the Yukon.*

APERÇU DES PLACERS DU YUKON, 2000

L'industrie des placers du Yukon a continué d'être un important secteur d'activité en 2000 malgré le fléchissement du cours des métaux précieux et la baisse progressive des activités d'exploration minière. Quelques 140 sites étaient en exploitation en 2000 (soit une diminution de 18 % par rapport à l'an dernier), pour un total de 450 emplois directs. Il n'en demeure pas moins que de nombreux emplois indirects (secteur des services et de l'hôtellerie-restauration) sont générés annuellement par les activités saisonnières d'exploitation des placers, en particulier dans les régions de Dawson et de Mayo. La plus grande partie des placers en opération se trouve dans le district minier de Dawson, ceux de Whitehorse et de Mayo venant en deuxième et en troisième place.

En 2000, plus de 85 % de l'or d'origine placérienne du Yukon a été produit dans le district de Dawson, qui comprend les bassins non-affectés par les glaciations de la rivière Klondike, la rivière Indian, de l'ouest du Yukon (Fortymile, Sixtymile, Moosehorn) et du cours inférieur de la rivière Stewart. Le reste de la production d'or provenait des régions à modelé glaciaire de Clear Creek, Mayo, Dawson Range, Kluane et Livingstone.

En 2000, la production des placers s'est chiffrée à 76 507 onces brutes (2 379 635 g), comparativement à 87,680 onces brutes (2 727 155 g) pour 1999, soit une diminution de 15 %. La valeur totale des revenus générés par la production placérienne du Yukon a également diminué, passant de 29,7 millions $C en 1999 à 25,4 millions $C cette année. Enfin, c'était la première fois que les exploitants devaient être munis de permis d'aménagement concernant les concessions qu'ils exploitent, en plus de l'habituel permis d'exploitation des eaux. Tous ces facteurs, conjugués au cours relativement bas de l'or et de la hausse des prix du carburant, ont créé des conditions économiques difficiles pour l'industrie des placers du Yukon.

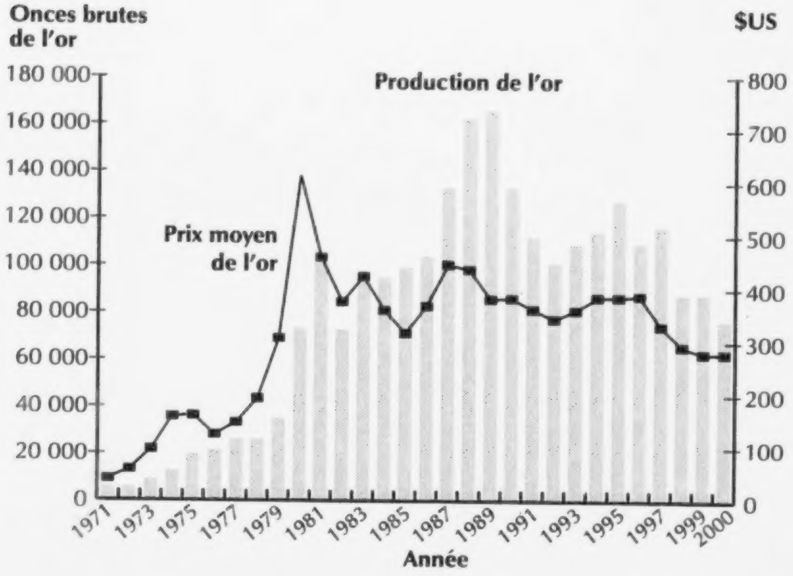

Figure 1. *Production des placers du Yukon par année et prix moyen de l'or en $US, 1971-2000.*

GOVERNMENT

Yukon Geology Program

Grant Abbott

Yukon Geology Program

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Yukon Geology Program

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OVERVIEW

Now in its fifth year, the Yukon Geology Program (Fig. 1) is a de facto Yukon Geological Survey consisting of two integrated and jointly managed offices with different administrative structures (Fig. 2). Federal funding is provided through the Exploration and Geological Services Division (EGSD), Yukon Region of the Department of Indian Affairs and Northern Development (DIAND), while Yukon Territorial Government (YTG) and cost-shared (YTG/DIAND) funding comes through the Mineral Resources Branch of the Department of Economic Development (YTG). The Geological Survey of Canada (GSC) also maintains an office with the Program.

Figure 1. *Yukon Geology Program staff, from left to right (top) Craig Hart, Anna Fonseca, Eric Peterson (bottom) Robert Deklerk, Charlie Roots, Tammy Allen, Mike Burke, Don Murphy, Grant Lowey, Lee Pigage, Ken Galambos, Leyla Weston, Jeff Bond, Panya Lipovsky, Jo-anne vanRanden, Bill LeBarge, Julie Hunt, Ali Wagner, Maurice Colpron, Danièle Héon, Monique Shoniker, Grant Abbott, Shirley Abercrombie, Gary Stronghill, Diane Emond and Gord Nevin.*

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The Yukon Geology Program is an informal and temporary organization that will be transformed into a Yukon Geological Survey when the responsibilities of the Northern Affairs Program of DIAND are devolved to YTG. Negotiations have met delays, and the target date for devolution has once again been moved ahead one year to April 1, 2002. The agreement in principal for the transfer is near completion and all parties expect negotiations to be successful.

During the past year, the Program benefited greatly from continued staff stability. YTG hired two GIS technicians, Gord Nevin and Gary Stronghill. Tammy Allen was appointed to a two-year term position to work on the Central Foreland NATMAP Project in La Biche River map area.

PROGRAM HIGHLIGHTS FOR 2000

FIELDWORK

The Yukon Geology Program is committed to providing a balanced complement of field projects, which provide stimulus to the mining and exploration industry and also takes the longer-term view to develop an understanding of the Yukon regional geological framework. The current state of fieldwork and locations of current field projects are shown in Figure 3.

The Yukon Geology Program continued to commit substantial resources to a joint Geological Survey of Canada-British Columbia Geological Survey Branch - Yukon Geology Program initiative, the Ancient Pacific Margin NATMAP (National Mapping Program) project. This project is a multidisciplinary effort to better

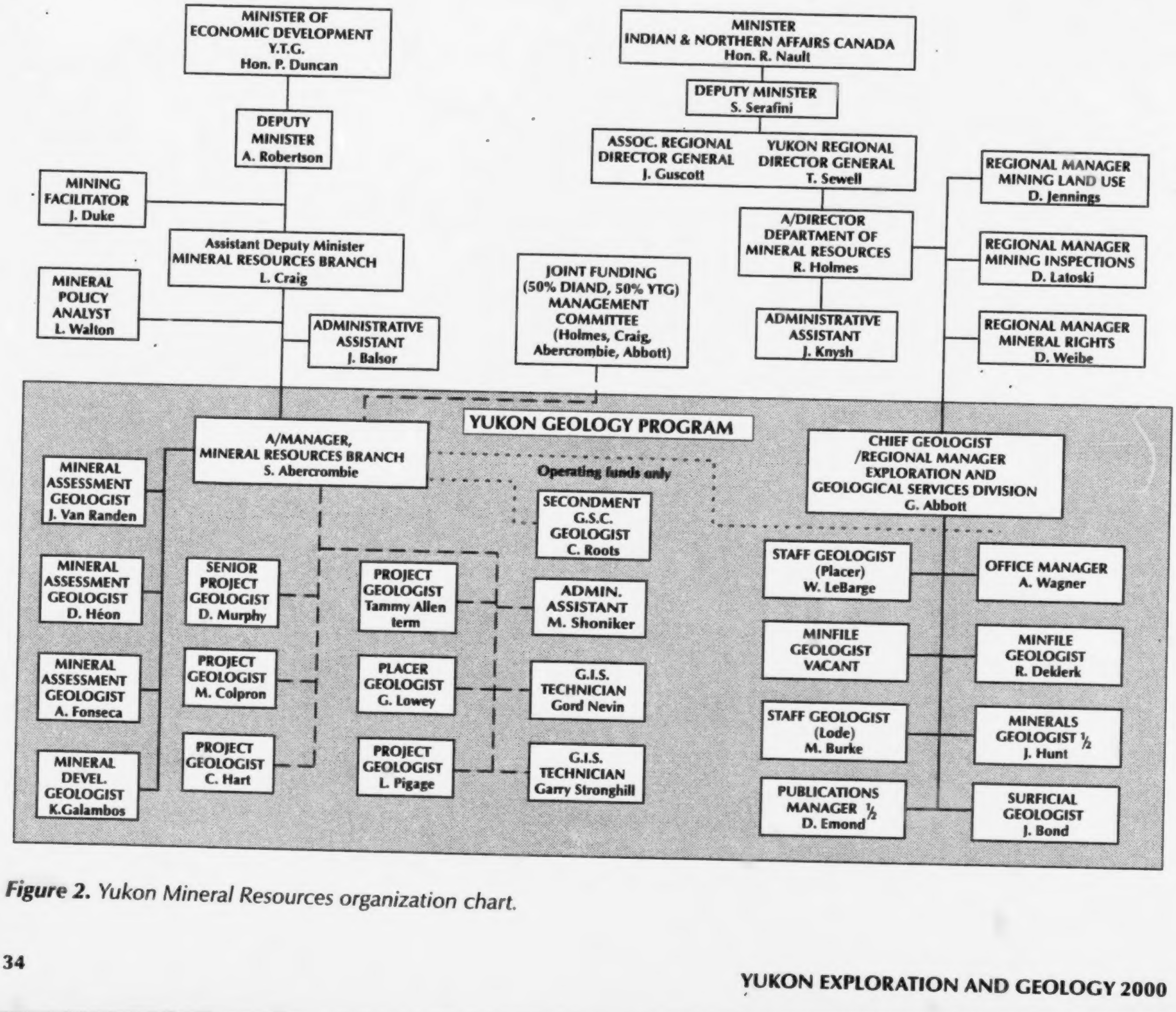
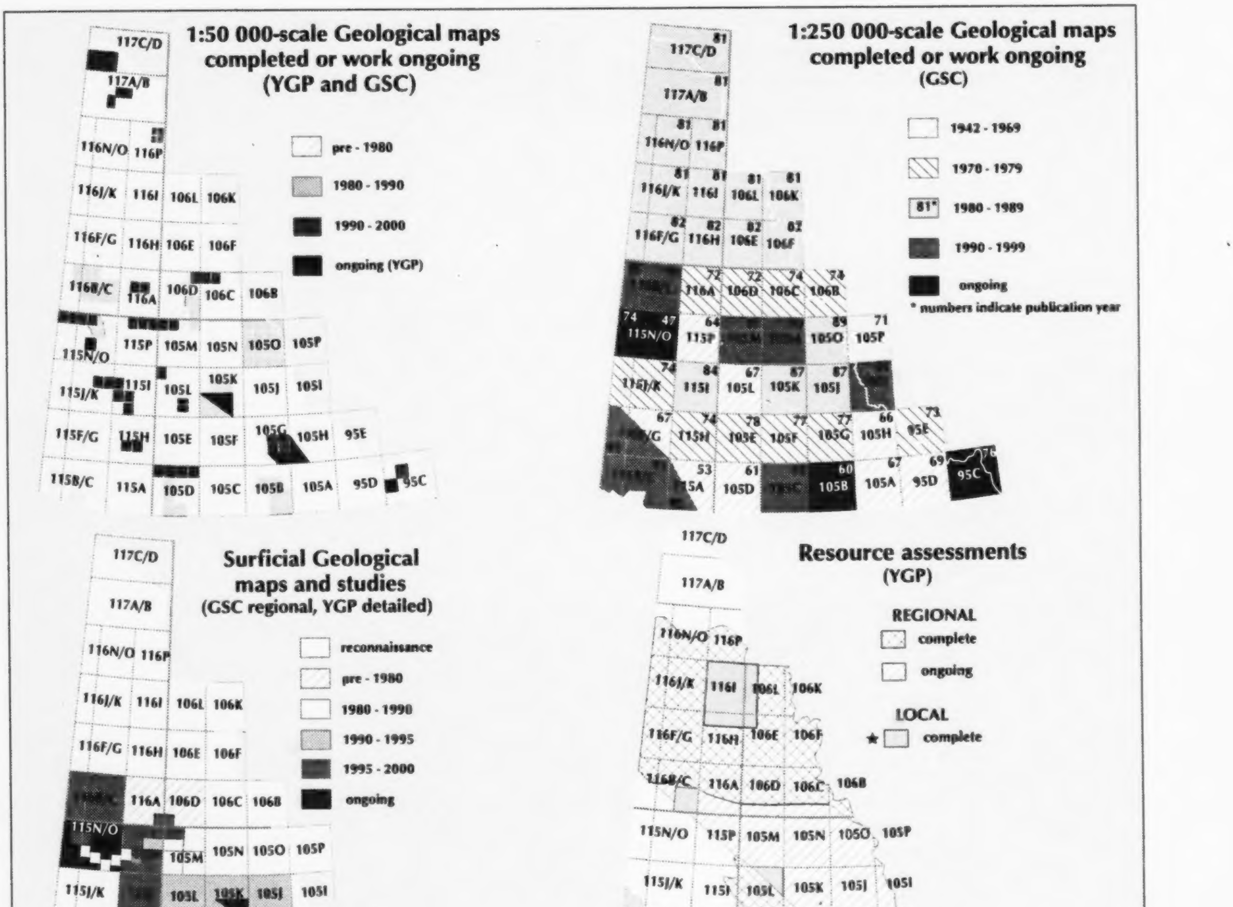

MINISTER OF ECONOMIC DEVELOPMENT Y.T.G. Hon. P. Duncan
DEPUTY MINISTER A. Robertson
MINING FACILITATOR J. Duke
Assistant Deputy Minister MINERAL RESOURCES BRANCH L. Craig
MINERAL POLICY ANALYST L. Walton
ADMINISTRATIVE ASSISTANT J. Balsor
MINISTER INDIAN & NORTHERN AFFAIRS CANADA Hon. R. Nault
DEPUTY MINISTER S. Serafini
ASSOC. REGIONAL DIRECTOR GENERAL J. Guscott
YUKON REGIONAL DIRECTOR GENERAL T. Sewell
A/DIRECTOR DEPARTMENT OF MINERAL RESOURCES R. Holmes
ADMINISTRATIVE ASSISTANT J. Knysh
REGIONAL MANAGER MINING LAND USE D. Jennings
REGIONAL MANAGER MINING INSPECTIONS D. Latoski
REGIONAL MANAGER MINERAL RIGHTS D. Weibe
JOINT FUNDING (50% DIAND, 50% YTG) MANAGEMENT COMMITTEE (Holmes, Craig, Abercrombie, Abbott)
YUKON GEOLOGY PROGRAM
A/MANAGER, MINERAL RESOURCES BRANCH S. Abercrombie
Operating funds only
CHIEF GEOLOGIST /REGIONAL MANAGER EXPLORATION AND GEOLOGICAL SERVICES DIVISION G. Abbott
MINERAL ASSESSMENT GEOLOGIST J. Van Randen
MINERAL ASSESSMENT GEOLOGIST D. Héon
MINERAL ASSESSMENT GEOLOGIST A. Fonseca
MINERAL DEVEL. GEOLOGIST K.Galambos
SENIOR PROJECT GEOLOGIST D. Murphy
PROJECT GEOLOGIST M. Colpron
PROJECT GEOLOGIST C. Hart
SECONDMENT G.S.C. GEOLOGIST C. Roots
PROJECT GEOLOGIST Tammy Allen term
PLACER GEOLOGIST G. Lowey
PROJECT GEOLOGIST L. Pigage
ADMIN. ASSISTANT M. Shoniker
G.I.S. TECHNICIAN Gord Nevin
G.I.S. TECHNICIAN Garry Stronghill
STAFF GEOLOGIST (Placer) W. LeBarge
MINFILE GEOLOGIST VACANT
STAFF GEOLOGIST (Lode) M. Burke
PUBLICATIONS MANAGER ½ D. Emond
OFFICE MANAGER A. Wagner
MINFILE GEOLOGIST R. Deklerk
MINERALS GEOLOGIST ½ J. Hunt
SURFICIAL GEOLOGIST J. Bond

Figure 2. Yukon Mineral Resources organization chart.



1:50 000-scale Geological maps completed or work ongoing (YGP and GSC)

pre - 1980
1980 - 1990
1990 - 2000
ongoing (YGP)

1:250 000-scale Geological maps completed or work ongoing (GSC)

1942 - 1969
1970 - 1979
81* 1980 - 1989
1990 - 1999
ongoing
* numbers indicate publication year

Surficial Geological maps and studies (GSC regional, YGP detailed)

reconnaissance
pre - 1980
1980 - 1990
1990 - 1995
1995 - 2000
ongoing

Resource assessments (YGP)

REGIONAL
complete
ongoing
LOCAL
★ complete

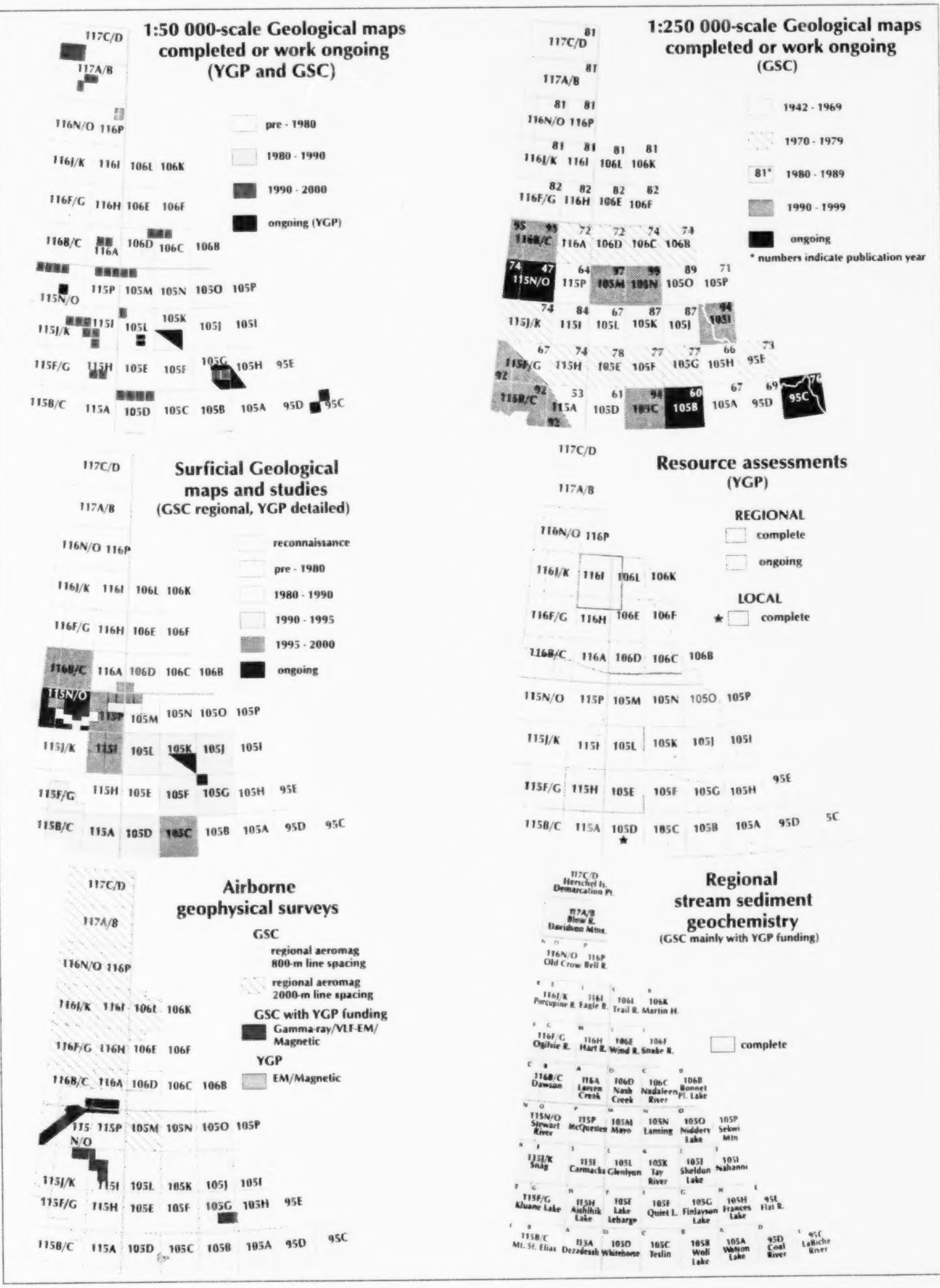
Airborne geophysical surveys

GSC
regional aeromag 800-m line spacing
regional aeromag 2000-m line spacing
GSC with YGP funding
Gamma-ray/VLF-EM/ Magnetic
YGP
EM/Magnetic

Regional stream sediment geochemistry (GSC mainly with YGP funding)

complete
117C/D Herschel Is. Demarcation Pt.
117A/B Blow R. Davidson Mtns.
116N/O Old Crow
116P Bell R.
116J/K Porcupine R.
116I Eagle R.
106L Trail R.
106K Martin H.
116F/G Ogilvie R.
116H Hart R.
106E Wind R.
106F Snake R.
116B/C Dawson
116A Larsen Creek
106D Nash Creek
106C Nadaleen River
106B Bonnet Pl. Lake
115N/O Stewart River
115P McQuesten
105M Mayo
105N Lansing
105O Niddery Lake
105P Sekwi Mtn
115J/K Snag
115I Carmacks
105L Glenlyon
105K Tay River
105J Sheldon Lake
105I Nahanni
115F/G Kluane Lake
115H Aishihik Lake
105E Lake Laberge
105F Quiet L.
105G Finlayson Lake
105H Frances Lake
95E Flat R.
115B/C Mt. St. Elias
115A Dezadeash
105D Whitehorse
105C Teslin
105B Wolf Lake
105A Watson Lake
95D Coal River
95C LaBiche River

Figure 3. Summary of available geological maps and regional geochemical and geophysical surveys in the Yukon.


1:50 000-scale Geological maps completed or work ongoing (YGP and GSC)
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1980 - 1990
1990 - 2000
ongoing (YGP)
1:250 000-scale Geological maps completed or work ongoing (GSC)
1942 - 1969
1970 - 1979
81* 1980 - 1989
1990 - 1999
ongoing
* numbers indicate publication year
Surficial Geological maps and studies (GSC regional, YGP detailed)
reconnaissance
pre - 1980
1980 - 1990
1990 - 1995
1995 - 2000
ongoing
Resource assessments (YGP)
REGIONAL
complete
ongoing
LOCAL
complete
Airborne geophysical surveys
GSC
regional aeromag 800-m line spacing
regional aeromag 2000-m line spacing
GSC with YGP funding
Gamma-ray/VLF-EM/ Magnetic
YGP
EM/Magnetic
Regional stream sediment geochemistry (GSC mainly with YGP funding)
complete

Figure 3. *Summary of available geological maps and regional geochemical and geophysical surveys in the Yukon.*

understand Yukon-Tanana and Kootenay terranes, arguably the least understood parts of the North American Cordillera.

The Yukon Geology Program contribution to NATMAP includes the ongoing work of Don Murphy in the Finlayson Lake massive sulphide district, fieldwork begun last year by Maurice Colpron in the Glenlyon area, mapping by Charlie Roots in the western half of Wolf Lake map area and the northern half of Jennings River map area in B.C. in partnership with Joanne Nelson and Mitch Mihalynuk of the B.C. Geological Survey Branch, and surficial studies by Grant Lowey in the Stewart River map area in conjunction with regional surficial studies by Lionel Jackson of the GSC.

Other parts of the Ancient Pacific Margin NATMAP include bedrock mapping of Stewart River map area in Yukon by Steve Gordey of the GSC, in southern B.C., regional mapping by Bob Thompson of the GSC, and in east-central Alaska, mapping by David Szumigala of the Alaska State Geological Survey, and mineral deposit studies by Cynthia Dusel-Bacon. Participation by numerous university researchers, graduate students and other specialists has greatly added to the depth and complexity of the project. In the Yukon, these include lithogeochemical studies in the Finlayson Lake area by Steve Piercey and Jim Mortensen of the University of British Columbia and mineral deposit studies by Suzanne Paradis of the GSC. Regular workshops and field trips are one of the main benefits of such a large and diverse project. This summer Jim Mortensen led a field trip along the Top of the World Highway, west of Dawson and into Alaska.

This year, the project received a substantial boost through additional funding provided by Natural Resources Canada's Targeted Geoscience Initiative (TGI). The extra funds were used to conduct an airborne multispectral and magnetometer survey across the Yukon-Tanana Terrane in Stewart River map area where bedrock exposure is especially poor. Preliminary approval was also given for TGI funding over the following two years. Plans for 2001 include accelerated regional mapping of Finalyson Lake map area north of the Tintina Fault, a till geochemical survey in the northern portion of the area between the Anvil and the Finlayson Lake massive sulphide districts, as well as additional geophysical surveys in the Stewart River map area. The proposal for 2002 includes accelerated mapping of the Yukon-Tanana portion of Glenlyon and McQuesten map areas and continued geophysical surveys in Stewart River map area. Priorities for the TGI proposal were determined largely from the results of the Second Yukon Geoscience Planning Workshop held in March, 1999 (Yukon Geoscience - Looking to the next Millennium, EGSD Open File 2000-14).

In order to accommodate increasing interest from YTG and industry in hydrocarbon-related geoscience, Tammy Allen and Lee Pigage joined GSC Calgary staff and university researchers on the Central Forelands NATMAP Project in La Biche River map area in southeast Yukon. The three-year project will better define the geologic framework of the area with the highest hydrocarbon potential in all of Yukon.

Another major effort by the Yukon Geology Program is to synthesize and enhance the geological database of the Anvil District. The Faro mine remains closed for the forseeable future, but the possibility remains for renewed exploration and mining at some point. Lee Pigage has completed bedrock mapping and expects to release a complete set of 11 geological compilation maps of the district at 1:25 000 scale by the spring of 2001. Jeff Bond has completed surficial mapping and a till geochemical survey and expects to release 11 final maps and a bulletin in the spring of 2001. Cliff Stanley has completed a lithogeochemical study of the Grizzly deposit, and will release a report later in the year.

Craig Hart continued his studies of Yukon gold occurrences; splitting his time between those related to the Tombstone intrusive suite northeast of the Tintina Fault, and those in the Dawson Range along trend from the Pogo Deposit in Alaska. Craig also assisted some of the students who received support from the YGP to study various aspects of Yukon gold deposits. These included Mark Lindsay and Julian Stephens, under the supervision of Tim Baker at James Cook University and John Mair at University of Western Australia; Erin Marsh and Seth Mueller under the supervision of Rich Goldfarb at the U.S. Geological Survey; and Scott Heffernan and Kelly Eamon under the supervison of Jim Mortensen at the University of British Columbia. Bedrock geology maps of the Dawson Range copper/gold belt, compiled from earlier mapping with the aid of recent geophysical surveys, are expected to be released in the spring of 2001.

Bill LeBarge and Mark Nowasad continued their studies of the relation between sedimentology, grain-size distribution, and water quality of effluent from placer deposits. Data gathered from this study should assist with the review of the Yukon Placer Authorization in 2001. The bulletin for the Mayo Placer project is expected to be released in the spring of 2001.

Julie Hunt who is now working half time, is nearing completion of her bulletin on Yukon volcanogenic massive sulphide deposits.

Grant Lowey and Darrel Long undertook a sedimentological study of Cretaceous sedimentary rocks near Ross River where dinosaur tracks were recently discovered.

EXTERNAL SUPPORT

Derek Thorkelson at Simon Fraser University continued his research on Proterozoic rocks and mineral deposits in the Wernecke Mountains with a small study of the Bear River dykes.

John Westgate at the University of Toronto continued tephrachronology studies in the Klondike area.

Robert Creaser and Dave Selby at the University of Alberta began a project to determine the feasibility of using Rhenium/Osmium systematics to determine the age of molybdenum in Yukon mineral deposits.

In order to make Regional Stream Geochemical data from the National Geochemical Reconnaissance Program more accessible, Peter Friske with the Geological Survey of Canada in Ottawa was funded to produce a template for display of existing Open File data in pdf format. We expect to begin releasing existing RGS data as pdf files in the new year.

INDUSTRY LIAISON AND SUPPORT

Mike Burke and Bill LeBarge, our main links to the exploration industry, continued to monitor Yukon hard-rock and placer mining and mineral exploration activity, visit active properties, review reports for assessment credit, and maintain the assessment report library.

YUKON MINFILE

Robert Deklerk maintains the Yukon MINFILE, Yukon's mineral occurrence database, which is another mainstay of the Yukon Geology Program. We have completed an upgrade from Microsoft Access Version 2 to Access 97 with major revision and simplification of the database structure. The updated digital version, with data revised to 1998, will be released on CD-ROM in the spring of 2001. New location maps produced in Arcview will accompany the release. The text version of MINFILE is available on our website and in hard copy through Exploration and Geological Services Division.

YUKON GEOPROCESS FILE

The Yukon GEOPROCESS File, under the direction of Diane Emond, is an inventory of information on geological process and terrain hazards, including 1:250 000 scale maps showing permafrost, landslides, recent volcanic rocks, structural geology, and seismic events and also includes references and summaries of bedrock and surficial geology. The GEOPROCESS File is intended as a planning aid for development activities and is available for most areas south of 66° latitude. The maps will soon be available in colour, on a single compact disk (CD).

H.S. BOSTOCK CORE LIBRARY

Mike Burke and Ken Galambos maintain the H.S. Bostock Core Library. The facility contains about 128,000 m of diamond drill core from about 200 Yukon mineral occurrences. Confidentiality of material is determined on the same basis as mineral assessment reports. Confidential core can be viewed with a letter of release from the owner. Rock saws and other rock preparation equipment are available to the public.

MINERAL RESOURCE ASSESSMENTS

The Yukon Mineral Resources Branch is responding to an increasing need for geological and metallogenic information to assist resolution of land use issues and conflicts. Some of the pressures have come from First Nation land claims negotiations, and localized land use conflicts such as one within the city limits of Whitehorse. Another important priority of the Yukon Government is to implement the Yukon Protected Areas Strategy, the goal of which is protection and withdrawal of representative land from industrial activity in all 23 ecoregions in the Yukon. YTG Economic Development intends to provide efficient and cost-effective input into the selection process by undertaking a Yukon-wide mineral potential study. Providing information on mineral potential at a regional scale will assist in guiding the selection of areas of interest, in order to minimize the impact on the access to mineral wealth.

A regional mineral potential exercise was conducted in the spring of 1999 for Northern Yukon, in the winter of 2000 for Cassiar Terrane and eastern Yukon-Tanana

Terrane, and in the fall of 2000 for Selwyn Basin. Expert panels estimated the probability of discovering new mineral deposits in geological tracts. Their estimations were processed through the Monte Carlo simulator and the resulting map displays the relative mineral potential of the tracts. The draft mineral potential maps will be used in the planning of the proposed Arctic Dempster Protected Area Strategy, Wolf Lake National Park, Nordenskiold Habitat Protection Area, and Ddhaw Ghro Special Management Area. The Cassiar Terrane and eastern Yukon-Tanana Terrane project provides a regional context for proposed protected areas within the Teslin Tlingit Council Traditional Territory, one of which is the Wolf Lake federal initiative. The study area covers most of the Traditional Territory and the portions of the Pelly Mountains and Yukon Southern Lakes ecoregions within it. The Selwyn Basin project will be completed by January 2001, and will be key to land claim negotiations and Yukon Protected Areas Strategy initiatives within Kaska Dena (Liard First Nation and Ross River Council) Traditional Territory. Compilation is ongoing for the next regional assessment to address Stikine and Cache Creek terranes. The assessment is planned for spring of 2001.

Field-based mineral deposit model studies were conducted in the Bonnet Plume Lake, Frances Lake, and La Biche River areas.

Due to the ongoing review of the implementation of Yukon Protected Areas Strategy, no detailed mineral resource assessments were conducted in 2000. Geological mapping, prospecting and sampling in anticipation of detailed mineral resource assessments were carried out in the Richardson Mountains, McArthur Range, and Nordenskiold River area.

Staff thoroughly review land claim selections and provide technical information to territorial land claim negotiators. Comments are provided on mineral potential, exploration history, mineral land tenure and access. Staff also updates and distributes the Yukon Land Status Map.

YUKON MINING INCENTIVE PROGRAM

The Yukon Government provides grants for grass roots exploration and initial development of properties. This year a total of $761,800 was distributed to 54 prospectors under the supervision of Ken Galambos.

PUBLICATIONS

The Yukon Geology Program is now converted to fully digital publishing. All geological maps are now printed and new publications are being produced from a digital format, on-demand. This advance will greatly reduce our printing and storage costs. An increasing number of Yukon Geology Program publications are available for download free of charge on our website at www.geology.gov.yk.ca/publications. Yukon Geology Program publications are published by Exploration and Geological Services Division, DIAND and are available at the address below.

Geoscience Information and Sales
c/o Whitehorse Mining Recorder
102-300 Main Street
Whitehorse Yukon Y1A 2B5
Ph. (867) 667-3266, Fax. (867) 667-3267
E-mail: geosales @inac.gc.ca

To learn more about the Yukon Geology Program, visit our homepage at http://www.geology.gov.yk.ca or contact us directly:

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Shirley Abercrombie, Acting Manager
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Government of Yukon
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APERÇU

Le Service de géologie du Yukon (fig. 1), qui en est maintenant à sa cinqième année d'existence, est dans les faits la commission géologique du Yukon et consiste en deux bureaux intégrés présentant des structures administratives différentes mais qui sont gérés conjointement (fig.2). Le financement par le fédéral est fourni par l'entremise de la Division des Services d'exploration et de géologie du ministère des Affaires indiennes et du Nord canadien (MAIN), alors que le financement par le territoire et à coûts partagés (GTY/MAIN) est obtenu par l'entremise de la Direction des ressources minérales du ministère de l'Expansion économique (gouvernement du territoire du Yukon (GTY)). La Commission géologique du Canada (CGC) maintient également un bureau auprès du Service.

Le Service de géologie du Yukon est une organisation informelle et temporaire qui sera transformée en commission géologique du Yukon lorsque les responsabilités du Programme des affaires du Nord seront dévolues au GTY. Il y a eu des retards dans les négociations et la date cible de cette dévolution a été devancée d'un an et fixée au premier avril 2002. L'entente de principe concernant le transfert est presque complétée et toutes les parties s'attendent à ce que les négociations soient couronnées de succès.

Le programme de géologie du Yukon compte de nombreuses fonctions dont les principales sont les suivantes : assurer la liaison entre l'industrie minérale et le gouvernement; tenir des bases de données géologiques telles que Yukon MINFILE (gîtes minéraux), Yukon GEOPROCESS FILE (processus géologiques et dangers du terrain) et Yukon Placer MINFILE (gisements placériens : cette base est toujours en cours d'élaboration); tenir un point de vente de cartes et de publications et une carothèque (H.S. Bostock Core Library); et enfin, promouvoir et exécuter de nouvelles recherches géologiques, et en publier les résultats.

La plupart des travaux de recherche géologique sont maintenant exécutés de concert avec des initiatives d'autres agences gouvernementales. Dans le cadre de CARTNAT (programme de cartographie géologique de l'ancienne marge du Pacifique) par exemple, la Commission géologique du Canada, la Direction de la Commission géologique de la Colombie-Britannique et le programme de géologie du Yukon mènent en ce moment un projet multidisciplinaire en vue de mieux comprendre les terranes de Yukon-Tanana et de Kootenay, soit les parties considérées comme les moins bien connues de la cordillère nord-américaine. Ces travaux, qui se déroulent au Yukon et en Colombie-Britannique, comprennent des travaux de cartographie géologique dans le district de Finlayson Lake, dans la région de Glenlyon, dans la région de Wolf Lake et dans la région de Jennings River (dans le nord de la Colombie-Britannique), de même que des travaux de cartographie géologique du socle et des dépôts superficiels dans la région de Stewart River. D'autres études connexes (par exemple sur les gîtes minéraux) menées au Yukon, en Colombie-Britannique et en Alaska par les géologues du programme de géologie du Yukon, des chercheurs universitaires, des étudiants de deuxième et de troisième cycle, et autres spécialistes ont grandement contribué à la valeur scientifique du projet. En outre, on a effectué un levé multispectral et magnétométrique aéroporté du terrane de Yukon-Tanana dans la région de Stewart River où le socle rocheux est très peu exposé.

Des travaux de cartographie géologique dans la région de LaBiche River, une région présentant un potentiel d'hydrocarbures, ont été aussi poursuivi dans le cadre de CARNAT 'Central Forelands'.

Au nombre des autres objectifs majeurs visés par le programme de géologie du Yukon, mentionnons celui consistant à synthétiser et à améliorer la base de données géologiques du district d'Anvil, initiative qui comprend la cartographie géologique du socle rocheux et des dépôts superficiels, et des levés géochimiques de till, en plus de l'étude des gites minéraux. Les indices aurifères du Yukon sont aussi à l'étude, l'attention portant sur ceux associés à la suite intrusive de Tombstone au nord-est de la faille de Tintina et sur ceux de la chaîne de Dawson, qui sont en ligne avec le gisement de Pogo en Alaska. Les études se poursuivent dans le domaine des placers, l'intérêt portant sur la relation entre la sédimentologie, la répartition granulométrique et la qualité de l'eau des effluents provenant des dépôts placériens. Une étude sédimentologique a aussi été menée dans des roches sédimentaires du Crétacé près de Ross River, dans une région où l'on a récemment découvert des pistes de dinosaures.

La Direction générale des Ressources minérales du gouvernement du Yukon répond actuellement à un besoin croissant d'information dans les domaines de la géologie et de la métallogénie, aux fins du règlement des questions et des conflits relatifs à l'aménagement du territoire, notamment la Stratégie des zones protégées du

Yukon. Le but de cette dernière est de réserver des terres représentatives pour les protéger de toute activité industrielle dans les 23 écorégions du Yukon. Le ministère du Développement économique du Yukon a annoncé une participation efficace et rentable au processus de sélection en entreprenant une étude du potentiel minéral de l'ensemble du territoire. Le programme de géologie du Yukon joue un rôle proactif en fournissant de l'information et des études sur le potentiel minéral à l'échelle régionale, afin de faciliter la sélection des sites d'intérêt et de minimiser ainsi l'impact sur l'accès aux richesses minérales.

Le gouvernement du Yukon accorde des subventions de prospection et de développement initial, dans le cadre du Programme d'encouragement pour l'exploitation minérale du Yukon. On a attribué cette année un total de 761 000 $ à 54 prospecteurs.

Les publications du programme de géologie du Yukon sont diffusées par la Division des services géologiques et d'exploration (MAINC). Un nombre croissant de publications du programme de géologie du Yukon sont aussi disponibles sans frais à : www.geology.gov.yk.ca. Tous les publications sont disponible à l'addresse suivante :

Bureau d'information et des ventes en géosciences
a/s Conservateur des registres miniers
Affaires indiennes et du Nord canadien
300 rue Main-bur.102
Whitehorse (Yukon) Y1A 2B5
Téléphone : (867) 667-3266
Courriel : geosales@inac.gc.ca

Pour en savoir plus long sur le Programme d'études géologiques du Yukon, visitez notre page d'accueil à http://www.geology.gov.yk.ca ou communiquez directement avec :

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Division de l'exploration et des services géologiques
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Courriel : gabbott@gov.yk.ca

Shirley Abercrombie, Gestionnaire intérimaire
Division des ressources minérales
Ministère de l'Expansion économique
C.P. 2703
Whitehorse (Yukon) Y1A 2C6
Téléphone : (867) 667-3438
Courriel : sabercro@gov.yk.ca

APPENDIX 1: RECENT PUBLICATIONS

BULLETIN

Thorkelson, D.J., 2000. Geology and mineral occurrences of the Slats Creek, Fairchild Lake and "Dolores Creek" areas, Wernecke Mountains (106D/16, 106C/13, 106C/14), Yukon Territory; Bulletin 10, three accompanying maps (1:50 000 scale).

OPEN FILES

Abbott, J.G. and Emond, D.S. (eds.), 2000. Yukon Geoscience - Looking to the Next Millenium; Open File 2000-14, 35 p.

Allen, T.L. and Pigage, L.C., 2000. Geological map of Pool Creek (95C/5), southeastern Yukon (1:50 000 scale); Open File 2000-11.

Bond, J.D., 2000. Surficial geological map and till geochemistry of Weasel Lake (105G/13), central Yukon (1:50 000 scale); Open File 2000-9.

Colpron, M., 2000. Geological map of Little Salmon Lake (parts of 105L/1, 2 & 7), central Yukon (1:50 000 scale); Open File 2000-10.

Hunt, J.A, Abbott, J.G and Hart, C.J.R., 2000. Preliminary metallogenic maps of Yukon (25 pages); Open File 2000-1.

Murphy, D.C., 2000. Preliminary geological map of part of the Klatsa River area (105H/3), southeastern Yukon (1:50 000 scale); Open File 2000-15.

Murphy, D.C., 2000. Preliminary geological map of part of the 'Tuchitua River - north' (105H/4), southeastern Yukon (1:50 000 scale); Open File 2000-16.

Murphy, D.C., 2000. Preliminary geological map of the Money Creek area (105H/5), southeastern Yukon (1:50 000 scale); Open File 2000-17.

Pigage, L.C., 2000. Geological map of Mount Mye (105K/6 NW), central Yukon (1:25 000 scale); Open File 2000-2.

Pigage, L.C., 2000. Geological map of Mount Mye (105K/6 NE) and Barwell Lake (105K/11 SE), central Yukon (1:25 000 scale); Open File 2000-3.

Pigage, L.C., 2000. Geological Map of Swim Lakes (105K/2 SE), central Yukon (1:25 000 scale); Open File 2000-4.

Pigage, L.C., 2000. Geological map of Swim Lakes (105K/2 NE), central Yukon (1:25 000 scale); Open File 2000-5.

Pigage, L.C., 2000. Geological map of Swim Lakes (105K/2 W), central Yukon (1:25 000 scale); Open File 2000-6.

Pigage, L.C., 2000. Geological map of Mount Mye (105K/6 E), central Yukon (1:25 000 scale); Open File 2000-7.

Pigage, L.C., 2000. Geological map of Blind Creek (105K/7 SW), central Yukon (1:25 000 scale); Open File 2000-8.

Pigage, L.C., 2000. Geological map of Rose Mountain (105K/5 NE), central Yukon (1:25 000 scale); Open File 2000-13.

YGP OUTSIDE ARTICLES

Flanigan, B., Freeman, C., McCoy, D., Newberry, R. and **Hart, C.**, 2000. Paleo-reconstruction of the Tintina gold belt - Implications for mineral exploration. *In:* The Tintina Gold Belt: Concepts, Exploration and Discoveries, British Columbia and Yukon Chamber of Mines, Special Volume 2, p. 35-48.

Flanigan, B., Freeman, C., McCoy, D., Newberry, R. and **Hart, C.**, 2000. Paleo-reconstruction of the Tintina gold belt, Alaska and Yukon Territory, Canada - Implications for mineral exploration. *In:* Geology & Ore Deposits 2000 - The Great Basin & Beyond, Reno-Sparks, Nevada.

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Yukon Mining Incentives Program Overview, 2000

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Galambos, K., 2001. Yukon Mining Incentives Program Overview, 2000. *In:* Yukon Exploration and Geology 2000, D.S. Emond and L.H. Weston (eds.), Exploration and Geological Services Division, Yukon, Indian and Northern Affairs Canada, p. 47-48.

Ninety applications were received by the program deadline of March 1, 2000. In an attempt to fund as many of the excellent proposals as possible, the Department of Economic Development, Yukon Government, added an extra $250,000 to the Yukon Mining Incentives Program (YMIP) contribution budget of $378,000. This increase in funding allowed the program to offer $761,800 to 54 applicants.

Approximately 75% of the successful projects contained a precious metal component, with 10% focussing on platinum group exploration (PGE). Those projects targeting gold, generally concentrated their exploration efforts near mid-Cretaceous intrusions within the Tintina gold belt. PGE exploration generally targeted the Kluane mafic-ultramafic belt in southwest Yukon.

Base metals exploration accounted for the remaining 25% of programs. Volcanogenic massive sulphide targets in the Yukon-Tanana Terrane were the focus of most of these exploration programs. The search for the porphyry source of skarn mineralization in the Whitehorse Copper Belt was also the target of a number of grassroots exploration and drill programs.

Highlights for the year include second-stage grassroots and initial drill programs on three base metals properties.

Kluane Drilling Ltd. drilled two holes on Rob Hamel's Hat property, located immediately north of the historic War Eagle pit in the Whitehorse Copper Belt. Drill hole HT-1 intersected 10.55 m of well mineralized skarn averaging 4.99% copper, 1.05 g/t gold and 40.28 g/t silver at a depth of 124.4 m (Fig. 1). Numerous other 1- to 1.2-m-wide intersections returned values from 1.44% to 7.22% copper. VLF-EM and I.P. anomalies suggest a possible 300-m-long extension to this zone. Trenches and mineralized float samples indicate that a porphyry copper-gold deposit may also exist on the property.

Pamicon Developments Ltd. conducted an extensive soil sampling and mapping program in the Bear Paw breccia area of the Clear Creek property, which is currently under

Figure 1. *Bornite mineralization cementing intrusive rock fragments in drill hole HT-1 on the Hat property. This interval assayed 11.25% copper and 1.92 g/t gold over 0.76 m.*

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option to Redstar Resources Corporation. This program lead to the core drilling of nine holes. Highlights were 71.5 m of 1.32 g/t gold, including 34.85 m of 2.00 g/t in hole BP00-03; 21.0 m of 1.00 g/t gold, including 6.3 m of 2.13 g/t gold in hole BP00-08; and 31.81 m of 2.30 g/t gold, including 18.31 m of 3.73 g/t in BP00-10 (Fig. 2).

Tanana Exploration identified two main zones of mineralization on their Fox property, southwest of Ross River. Detailed prospecting and sampling in the Avalanche Ridge area revealed a 200 m x 300 m area of mineralized float, some of which returned combined zinc-lead values in excess of 25%. The Ram zone has been identified as one source of the large mineralized float boulders found in Brie Creek (Fig. 3). Elevated zinc-lead-silver values are reported over widths of up to 5 m. More quartz-rich zones often assay >1% copper with anomalous gold. High-grade vein and fracture filling mineralization in the area returned values from 1.26 to 20.2 g/t gold.

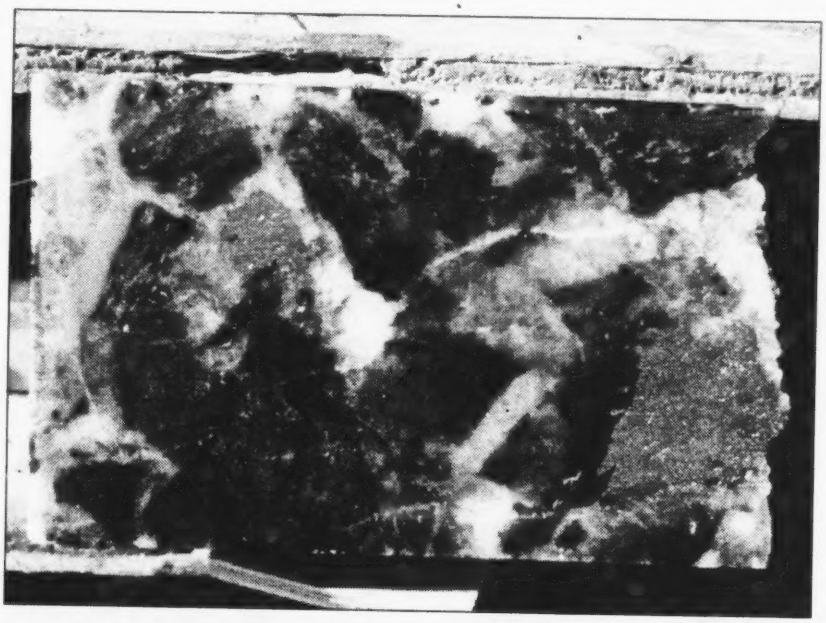

Figure 2. *Typical gold-bearing quartz-breccia mineralization from this year's drilling at Clear Creek. Photo by M. Burke.*

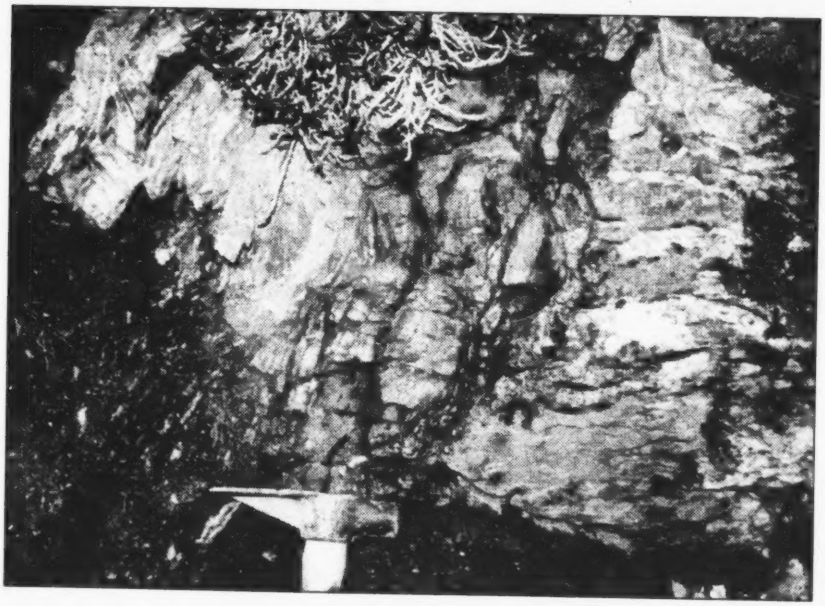

Figure 3. *Copper-rich mineralization in outcrop at the Ram zone. Photo by M. Burke.*

Robert E. Leckie Awards for Outstanding Reclamation Practices

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Mining Land Use Division, Indian and Northern Affairs Canada

Pelletier, K., 2001. Robert E. Leckie Awards for Outstanding Reclamation Practices. *In:* Yukon Exploration and Geology 2000, D.S. Emond and L.H. Weston (eds.), Exploration and Geological Services Division, Yukon, Indian and Northern Affairs Canada, p. 49-50.

The Robert E. Leckie Awards for outstanding reclamation practices in the Yukon, both for quartz and placer exploration or mining, were first established in November, 1999. The two awards are given for reclamation and site restoration efforts that go well beyond what is required by law, either by reclaiming land for which there is no obligation to reclaim, adding features to the land that have enhanced the area and local community, or returning mined land to a condition that is not only physically sound but aesthetically pleasing. The awards were named after the late Robert (Bob) Leckie, a former mining inspector for Indian and Northern Affairs Canada, who passed away in November, 1999 (see Yukon Exploration and Geology 1999).

The 2000 Robert E. Leckie Award for Outstanding Reclamation Practices in Quartz Exploration and Mining goes to Cash Resources Ltd. The company has been active in the Yukon since 1985 and has long been recognized as a leader in environmental stewardship and in community involvement. The company has continuously contributed to the knowledge base regarding successful reclamation methods in the north through hosting site visits and giving presentations at reclamation workshops.

Figure 1. *Walking a backhoe across the tundra to the Killer Gold property, Killerman Lake area.*

Cash Resources Ltd. is recognized for using exceptional operational and restoration procedures during the Killer Gold exploration project near Killerman Lake in 1995. This was prior to being required to do so by the Yukon Mining Land Use Regulations which came into effect in 1998. Killerman Lake is located approximately 45 km northwest of Haines Junction and the Kluane National Park.

From the onset of the project, local First Nations were involved in the planning and implementation stages. Access was achieved by walking the backhoe over a tundra landscape for a distance of 26 km while leaving a minimal trace (Fig. 1). The timing of the project was designed to specifically avoid conflicts with sheep lambing, caribou migration and the local outfitter. In addition, the company co-funded a study with the Yukon Government on the effects of mineral exploration activities in areas of sheep habitat. During the exploration activity, drill pads were constructed by hand, the drill was moved by helicopter to minimize ground disturbance, and drill moves were scheduled to avoid bedding times for local sheep. Trenches were buried as soon as sampling was completed, and natural re-vegetation has been successful in the challenging tundra environment.

Grew Creek Ventures Ltd. is the recipient of the 2000 Award for Outstanding Placer Mining Reclamation Practices. When Dave Marsters of Grew Creek Ventures Ltd. moved to Hunker Creek in 1998, the ground he occupied had previously been extensively mined since the turn of the century, but had never been reclaimed. Tailings from dredging and small-scale bulldozer mining, as well as old equipment and waste oil products, were found everywhere. In 1999 and 2000, the company accomplished 1.2 km of excellent restoration work, reclaiming disturbances from current mining activities as well as all previous mining activities. All tailings from the current and past operations were levelled, contoured and covered with 'black muck' to insure rapid natural re-vegetation (Fig. 2). Stream restoration at the site is exceptional and was accomplished well beyond the requirement by permit conditions. Small isolated ponds were created to enhance local habitat.

Congratulations to Cash Resources Ltd. and Grew Creek Ventures Ltd., the 2000 recipients of the Robert E. Leckie Reclamation Awards in the Yukon.

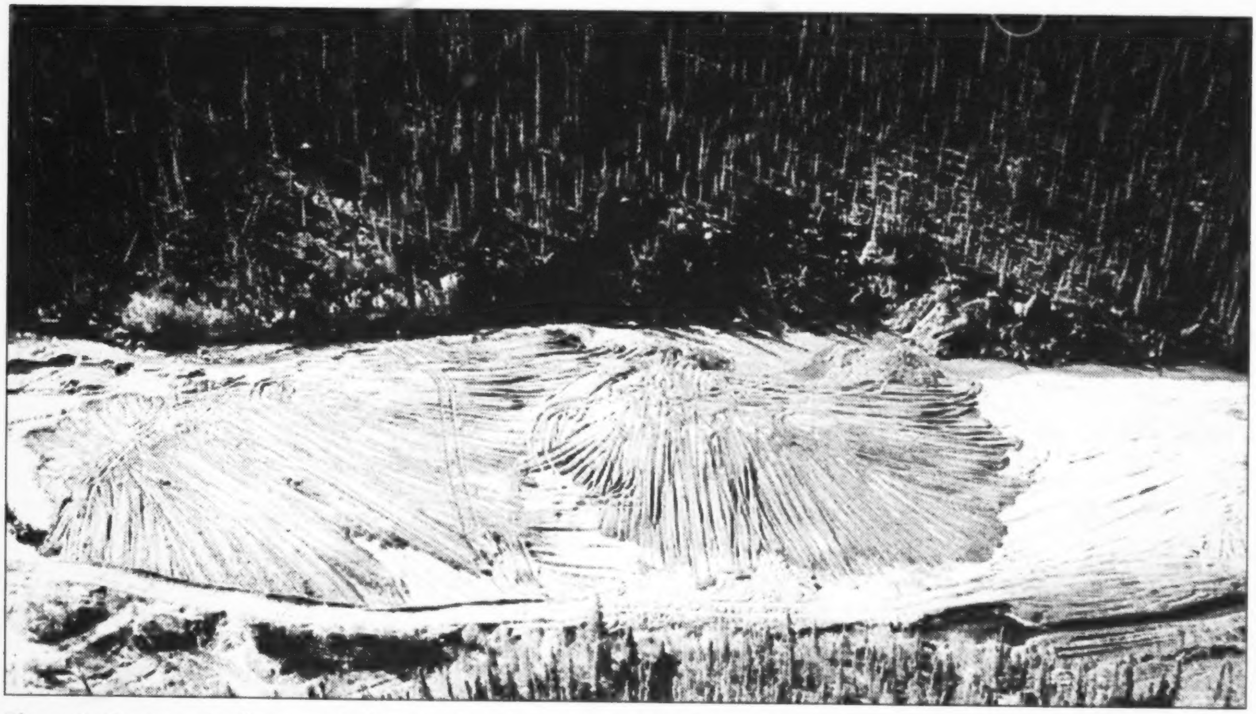

Figure 2. *Contoured tailings at Hunker Creek are covered with 'black muck' to enhance natural revegetation.*

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Preliminary geology of the Pool Creek map area (95C/5), southeastern Yukon[1]

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Allen, T.L., Pigage, L.C. and MacNaughton, R.B., 2001. Preliminary geology of the Pool Creek map area (95C/5), southeastern Yukon. *In:* Yukon Exploration and Geology 2000, D.S. Emond and L.H. Weston (eds.), Exploration and Geological Services Division, Yukon, Indian and Northern Affairs Canada, p. 53-72

ABSTRACT

Fieldwork in the northwest corner of Pool Creek map area (NTS 95C/5) during the summer of 2000 distinguished North and South areas with distinct stratigraphies and deformation histories. The South area is underlain mainly by siliciclastic sedimentary rocks (1100 m total thickness in three units) of uncertain age (Proterozoic ?). North area stratigraphy (1800 m total thickness in seven units) ranges in age from Ordovician to Mississippian and consists of an interbedded succession of carbonates, sandstones, siltstones, and shales. Major shale units in the succession are correlated with Road River and Earn groups.

Strata in both areas have been intruded by a north-trending, unfoliated, Eocene (?) syenite. The syenite has a thin contact metamorphic aureole consisting of skarn, gossan, and biotite hornfels.

Deformation in the South area is characterized by broad, northeast-trending, subhorizontal folds, which are likely coeval with syenite intrusion. Units in the North area are deformed into tight, overturned, north-plunging, east-verging folds with a well developed, axial planar, slaty cleavage in the hinge zones. North area deformation probably predates syenite intrusion.

Our fieldwork confirmed previously reported U-Th-REE prospects associated with the syenite and favourable stratigraphy for sedimentary-exhalative targets in the North area.

RÉSUMÉ

Les travaux de terrain exécutés durant l'été 2000 dans l'angle nord-ouest de la région de Pool Creek (95C/5) ont permis de différencier une zone Nord et une zone Sud ayant une stratigraphie et une histoire déformationnelle distinctes. La zone Sud est composée principalement de roches sédimentaires silicoclastiques (trois unités d'une épaisseur totale de 1100 m) d'âge incertain (Protérozoïque). La stratigraphie de la zone Nord (sept unités d'une épaisseur totale de 1800 m) s'échelonne de l'Ordovicien au Mississippien. Elle se compose d'une séquence interstratifiée de carbonates, de grès, de siltites et de shales. On a établi une corrélation entre les principales unités de shales de cette séquence et les groupes de Road River et d'Earn.

Dans les deux zones, les strates ont subies l'intrusion d'une syénite non foliée, d'âge Éocène (?), orientée vers le nord. Cette syénite est entourée d'une fine auréole de métamorphisme de contact comprenant des skarns, des chapeaux de fer et des cornéennes à biotite.

Dans la zone Sud, la déformation se caractérise par de larges plis subhorizontaux de direction nord-est, sans doute contemporains de l'intrusion de syénite. Les unités présentes dans la zone nord sont déformées en plis fermés et déversés plongeant vers le nord et orientés vers l'est accompagnés d'une schistosité ardoisière à plan axial bien développée dans les zones de charnières. La déformation présente dans la zone Nord est sans doute antérieure à l'intrusion de la syénite.

Les travaux de terrain ont confirmé la présence de zones à potentiel pour l'uranium, le thorium et des éléments des terres rares dans et près de la syénite, ainsi qu'une stratigraphie favorable à la présence de cibles sédimentaires-exhalatives dans la zone Nord.

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INTRODUCTION

The Central Foreland NATMAP Project is a multi-disciplinary collaborative mapping project to update the geological mapping of the Foothills of northeastern British Columbia and the Liard Basin region of the southern Northwest Territories and adjacent Yukon Territory. The Yukon Geology Program joined the project during the 2000 field season to begin 1:50 000-scale bedrock mapping in the Pool Creek map area (95C/5), southeastern Yukon. This study will better define the stratigraphy, structure, and mineral and hydrocarbon potential of the area.

This report of the stratigraphy and structure of part of the Pool Creek map area is based on twenty days of fieldwork during the summer, 2000. Descriptions are based on field and hand-sample observations. Selected samples have been submitted for geochemical and chronological analysis. Stratigraphic thicknesses are derived from interpretive cross-sections. Further fieldwork is planned for 2001.

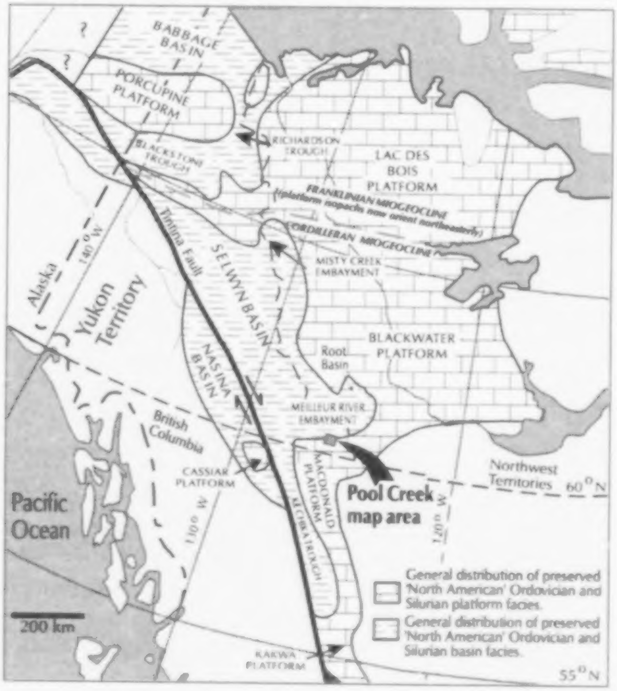

?
?
BABBAGE BASIN
PORCUPINE PLATFORM
RICHARDSON TROUGH
BLACKSTONE TROUGH
LAC DES BOIS PLATFORM
FRANKLINIAN MIOGEOCLINE (platform isopachs now orient northeasterly)
CORDILLERAN MIOGEOCLINE
MISTY CREEK EMBAYMENT
Tintina Fault
SELWYN BASIN
140° W
Alaska
Yukon Territory
BLACKWATER PLATFORM
Root Basin
NASINA BASIN
MEILLEUR RIVER EMBAYMENT
British Columbia
CASSIAR PLATFORM
MACDONALD PLATFORM
KECHIKA TROUGH
Northwest Territories
60° N
Pool Creek map area
120° W
130° W
Pacific Ocean
200 km
General distribution of preserved 'North American' Ordovician and Silurian platform facies.
General distribution of preserved 'North American' Ordovician and Silurian basin facies.
KAKWA PLATFORM
55° N

Figure 1. *Location of Pool Creek (NTS 95C/5) map sheet in Yukon Territory. General distribution of platform and basin facies of Cordilleran miogeocline are indicated. Modified from Cecile et al. (1997).*

LOCATION AND ACCESS

The field area (Fig. 1) is located 135 km west-northwest of Fort Liard, Northwest Territories, and 165 km east-northeast of Watson Lake, Yukon Territory, within the Liard Plateau physiographic region (Bostock, 1948). Topography consists of low rounded hills with incised stream drainages. Elevations range from 1500 feet (460 m) to 4200 feet (1280 m). The area is heavily forested with a single, north-trending ridge extending above tree line for ten kilometres. Beaver River flows southeast through the area. Bedrock exposure is 10% or less with most outcrop occurring as cliffs along Beaver River.

Access is by helicopter from Fort Liard and by canoe on Beaver River. Fieldwork was completed primarily by foot traverses from base camps on the treeless ridge and along the Beaver River.

PREVIOUS WORK

The Geological Survey of Canada conducted 1:253 440-scale bedrock mapping in La Biche River map area (95C) during 1957 as part of Operation Mackenzie (Douglas and Norris, 1959). The geology of the area was further updated based on fieldwork completed in 1972 (Douglas, 1976).

Mineral exploration between 1973 and 1986 identified U-Th-REE prospects in the contact metamorphic aureole of the Pool Creek syenite, sedimentary exhalative (SEDEX) targets in lower Paleozoic shales, and barite veins in Devonian carbonates (Yukon MINFILE, 1997). Exploration has been limited since 1986. The Beaver River is currently an area of high conservation interest.

REGIONAL GEOLOGY

Pool Creek map area is located in the transition zone (Fig. 1) between lower Paleozoic shallow-water carbonates of Macdonald Platform and lower Paleozoic fine-grained, deep-water, siliciclastic sediments of Meilleur River Embayment in Selwyn Basin (Cecile et al., 1997). These facies belts were deposited within the Cordilleran miogeocline, a depositional prism of sedimentary rocks of Precambrian to Middle Jurassic age along the relatively stable continental margin of western North America (Abbott et al., 1986).

Cecile et al. (1997) recognized a series of northeast-trending lineaments dividing the Cordilleran miogeocline into distinct structural blocks. The most prominent of these features is the Liard Line in northeastern British Columbia, interpreted to be a major crustal transfer fault in the ancient west North American margin. More recently, Morrow and Miles (2000) proposed the existence of a similar northeast-trending Beaver River structure extending through the Pool Creek area. They suggest 15-20 km of dextral strike-slip displacement along the Beaver River structure based on geological and geophysical arguments.

POOL CREEK MAP AREA GEOLOGY

INTRODUCTION

Geological mapping during the 2000 field season was restricted to the northwest corner of the Pool Creek map area (Fig. 2). Ten sedimentary units with a combined thickness of greater than 2900 m and ranging in age from Proterozoic (?) to Mississippian were identified (Fig. 3).

Mapping delineated stratigraphically and structurally distinct North and South areas (Figs. 2, 4, 5). Stratigraphic Units 1-3 (aggregate thickness 1100 m) are restricted to the South area, and stratigraphic Units 4-10 (aggregate thickness 1800 m) occur in the North area. Units in the South area are unfossiliferous and not readily correlated with regional stratigraphy, but may be Proterozoic (?) in age. Units in the North area range from Ordovician through Mississippian (?) and correlate with regional stratigraphy. Strata in both areas (Figs. 2, 4, 5) are intruded by a north-trending Eocene (?) syenite (Pool Creek syenite) which is exposed for a strike length of approximately 7 km.

STRATIGRAPHY

Unit 1

Unit 1 occurs immediately south of the syenite intrusion in the northwest portion of the Pool Creek map area (Fig. 4) and is at least 550 m thick. It is unfossiliferous and its basal contact is not exposed.

The primary lithology is light to dark grey, finely planar-laminated, noncalcareous, fine-grained quartz sandstone (Fig. 6). Laminae are 1-2 mm thick and are spaced approximately 1 cm apart. Typically, the sandstone breaks into angular blocks with smooth bedding plane surfaces. Intervals of dark grey to black quartz sandstone to siltstone up to several metres thick occur locally. Minor intervals up to 1 m thick containing soft sediment deformation folds and intraformational breccias occur throughout the unit. Locally, crosscutting fractures in Unit 1 are stained red by hematite dust. The uppermost 30 m of the unit is a massive, pale grey to white, sugary, quartz sandstone. Bedding in this massive interval is only rarely visible as poorly developed faint colour banding. In one outcrop area, this massive sandstone contains a 0.5-m-thick interval of intraformational conglomerate with poorly sorted quartz sandstone clasts up to 10 cm across in a white sand matrix.

The planar bedding of Unit 1 denotes a quiet depositional environment below wave-base. Deposition is interpreted as near offshore because of the thick accumulation of sand-sized material. Exact water depth in the depositional area cannot be determined. The occurrence of soft sediment deformation features and intraformational breccias indicates local transport on a slight slope.

Unit 1 is stratigraphically the lowest unit mapped in the South area and was assigned to the Carboniferous Mattson Formation by Douglas (1976). However, it differs markedly from the Mattson Formation in colour and lithology and lies stratigraphically below Neoproterozoic (?) strata of Map Unit 3 (see below) without apparent structural interruption. Therefore, Map Unit 1 is tentatively assigned a Proterozoic age.

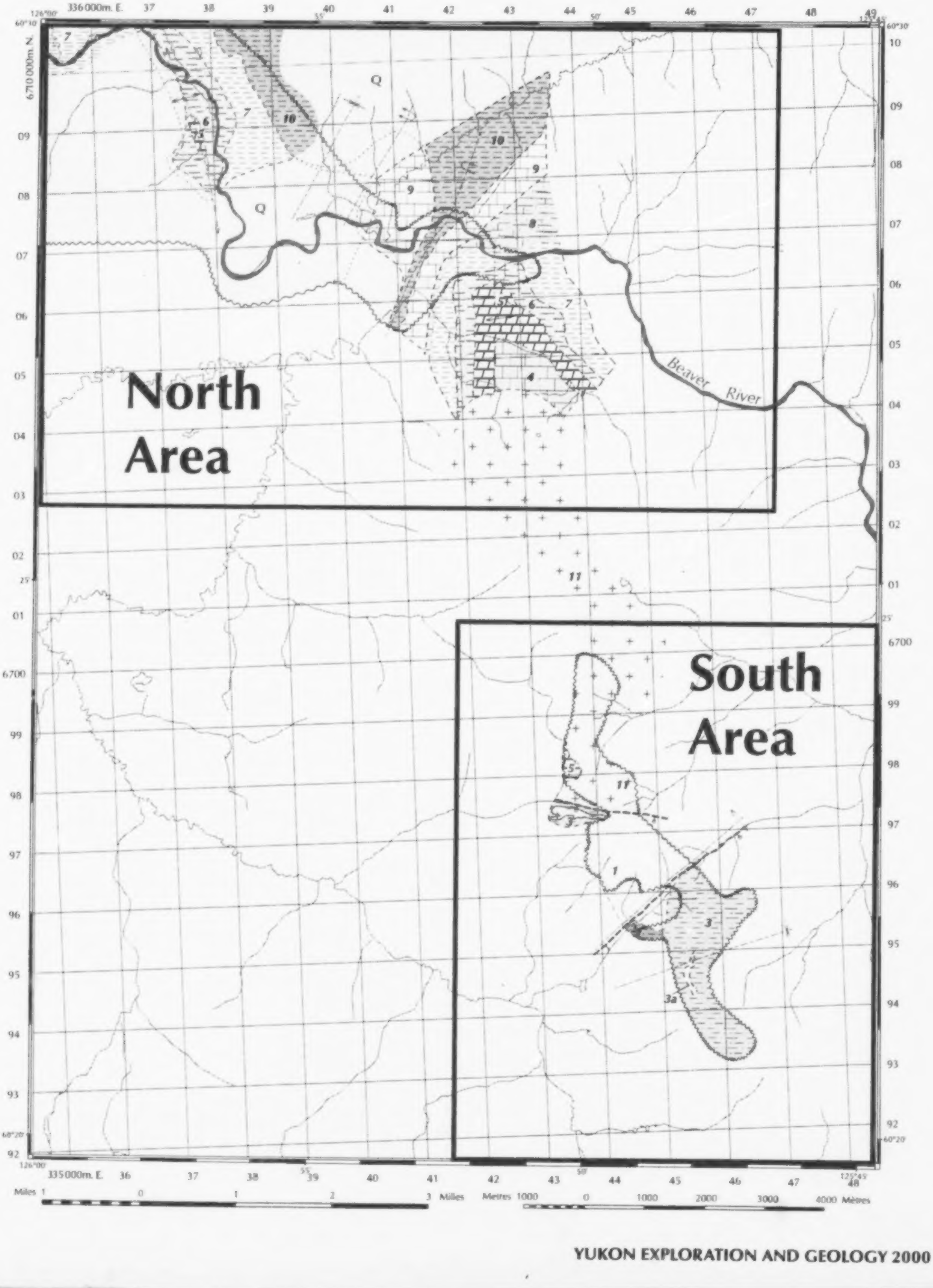
Unit 2

Conformably overlying Unit 1 is black, noncalcareous, finely laminated, fissile, silty shale constituting Unit 2 (Fig. 7). Unit 2 is poorly exposed south and west of Unit 1 in the South area. The shale contains wavy, 1-mm-thick parallel laminae of medium grey, noncalcareous siltstone spaced every 2 to 10 mm.

The base of Unit 2 contains interbeds of Unit 1 lithology up to 20 cm thick over a 5-m interval. The upper contact is not exposed. The Figure 2 unit has an interpreted maximum thickness of 60 m and apparently pinches out to the north. As with Unit 1, the planar bedding indicates deposition in a quiet environment below wave-base. Abundant organic carbon denotes euxinic conditions during deposition.

No fossils were found in Unit 2. Douglas (1976) interpreted it as Devonian Besa River Formation. However it lacks the distinctive weathering character of that formation and occurs without structural interruption beneath Map Unit 3, interpreted as Proterozoic by

Figure 2 legend and caption at right.


North Area
South Area
Beaver River
Q
1
3
3a
4
5
6
7
8
9
10
11
126°00'
125°45'
60°30'
60°25'
60°20'
55'
50'
336000m. E.
335000m. E.
6710000m. N.
6700
Miles 1 0 1 2 3 Miles
Metres 1000 0 1000 2000 3000 4000 Metres

LEGEND

QUATERNARY

Q	Unconsolidated alluvium, colluvium and glacial deposits.

EOCENE?

11	Pink with lesser dark green, medium to coarsely crystalline syenite. Predominantly randomly oriented pink potassium-feldspar crystals with lesser dark green hornblende.

North Area

DEVONIAN to MISSISSIPPIAN
EARN GROUP

10	Dark grey to black, carbonaceous shale, siltstone, chert and siliceous limestone. Weathers recessively and pale bluish-grey.

MIDDLE DEVONIAN

9	Buff- to grey-weathering, medium grey, argillaceous limestone. Micritic with the exception of local thin grainstone beds (<10 cm) containing one- and two-holed crinoids. Black calcareous shaly partings between more resistant limestone beds.
8	Buff-weathered, platy, dark grey siltstone, very fine-grained sandstone and silty shale. Strata are dolomitic, finely micaceous and parallel laminated.

ORDOVICIAN to SILURIAN
ROAD RIVER GROUP

7	Dark grey to black, graptolitic, locally calcareous, shale or siltstone with lesser very fine-grained sandstone, chert, and limestone. The unit weathers recessively and contains few brachiopods and crinoids.

LOWER PALEOZOIC (AGE UNCERTAIN)

6	Grey to buff, quartz-rich sandstone to pebbly grit. Grains are subround to round. Contains beds up to 2 m thick of heavily burrowed, slightly dolomitic, very fine-grained sandstone and siltstone.
5	Mottled light to dark grey dolostone. Micritic to sucrosic, local black chert nodules present. Weathers light brownish-grey to buff.
4	Grey- to tan-weathering limestone. Massive, finely crystalline, and barren of fossils (after Burt, 1983).

PRECAMBRIAN TO LOWER PALEOZOIC (AGE UNCERTAIN)

South Area

3	Green to grey, locally greyish-red, banded siltstone with very fine-grained sandstone. Sandstone interbeds (1-5 cm thick) are quartzose, internally laminated, and graded. The unit includes soft sediment deformation and minor green matrix-supported conglomerate beds.
3a	Greyish-red, clast-supported conglomerate. Clasts are subangular to subround, commonly pebble to cobble size (maxium 40 cm across). Clasts are predominantly basalt with lesser amounts of vein quartz, carbonate, and sandstone. The unit is up to 20 m thick.
2	Black silty shale, platy to fissile. Weathers medium grey to rusty. Contains wavy parallel laminae spaced 2 to 10 mm.
1	White to light grey quartzite. Very fine-grained to sugary, massive to faintly laminated.

SYMBOLS

Geological contacts (defined, approximate, assumed)

Fault, displacement unknown (defined, approximate, covered)

Normal fault, displacement unknown (approximate)

Limit of mapping

Metamorphic hornfels line (symbol on higher grade side)

Bedding

Dominant foliation (transposition foliation; commonly parallel to compositional layering): inclined, vertical

Fold axial surface trace (anticline: upright, overturned; syncline: upright, overturned)

Line of cross-section

Gossan

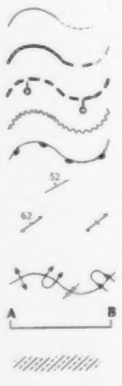


Figure 2. *Geologic map of northwest corner of Pool Creek map sheet, indicating locations of North and South areas. Grid spacing is 1 km.*

Douglas and Norris (1959). Map Unit 2 is therefore provisionally considered to be Proterozoic.

Unit 3

Unit 3 is the most areally extensive unit studied in the South area, underlying the main ridges south of the syenite intrusion. It consists predominately of greyish-green, banded, argillaceous siltstone with thin cream-coloured, locally calcareous, very fine-grained sandstone interbeds. Unit 3 is approximately 500 m thick. The lower contact with Units 1 and 2 is unexposed, but is interpreted as unconformable because Unit 2 is not present on the ridge immediately south of the syenite. The upper contact was not observed.

One of the authors (R. MacNaughton) measured a 372-m-thick stratigraphic section through part of Unit 3 (Figs. 4 and 8). The measured section is dominated by three facies associations outlined below.

Facies Association 1 (green argillite) is dominated by thin-laminated, medium- to dark-green-weathering siltstone and argillite with thin-laminated, pale-green- to greenish-grey-weathering siltstone interbeds (Fig. 9). The siltstone interbeds are 1-5 cm thick and make up 5-50% of the unit. These two lithologies constitute 80% or more of the facies association's total volume. Pale greenish-grey-weathering, very fine sandstone locally comprises up to 20% of this facies association, but more commonly accounts for less than 10%. Sandstone occurs as sharp-based stringers, laminae, or very thin (rarely thin) beds and is commonly normally graded. Parallel lamination and current ripple cross-lamination occur sporadically. Soft-sediment deformation is common and ranges from loading and convolute bedding, to intraformational truncation surfaces and slump masses (containing slump folds) up to several metres thick. Slump folds are commonly isoclinal and oriented at a low angle to bedding (Fig. 10). This facies association accounts for over half of the total thickness of the measured section.

In an outcrop outside the measured section, this facies contains a 15-m-thick interval where the dominant argillaceous siltstone is maroon instead of green. The

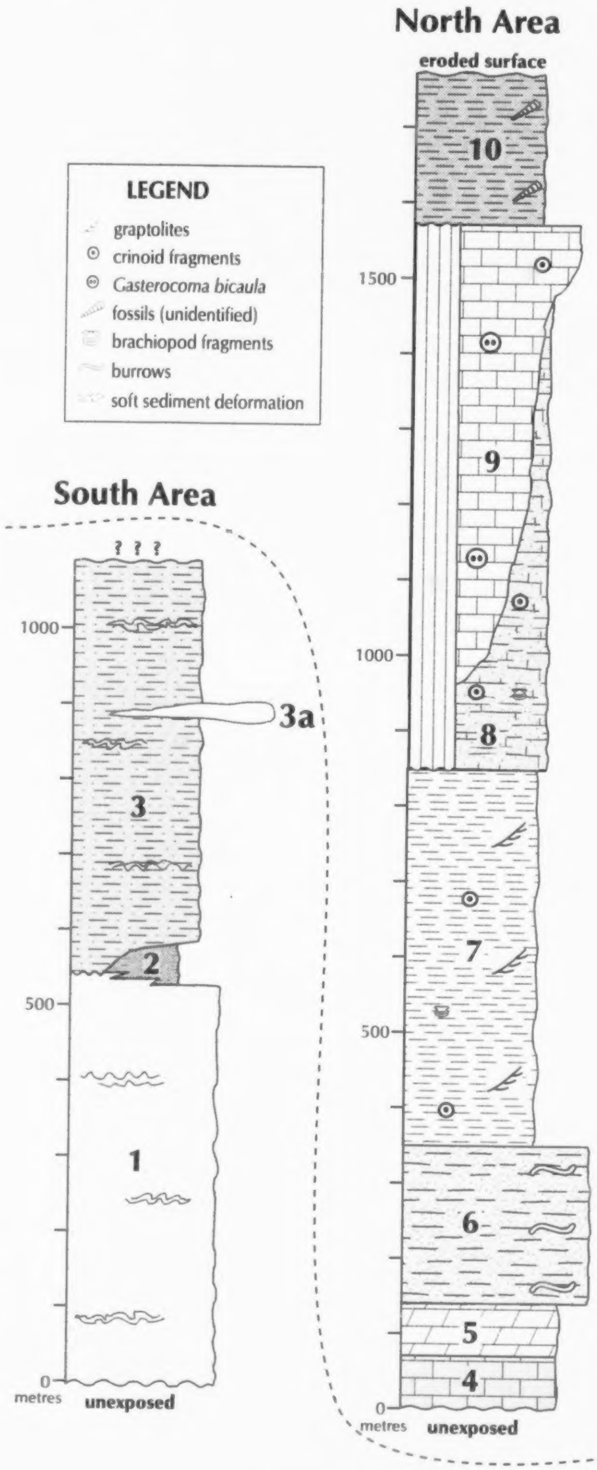


Figure 3. *Generalized stratigraphic section of Pool Creek sedimentary units. Units 1-3 occur in the South area. Units 4-10 occur in the North area. For patterns and unit descriptions, see legend from Figure 2. Wavy line and vertical line pattern indicate unconformity.*

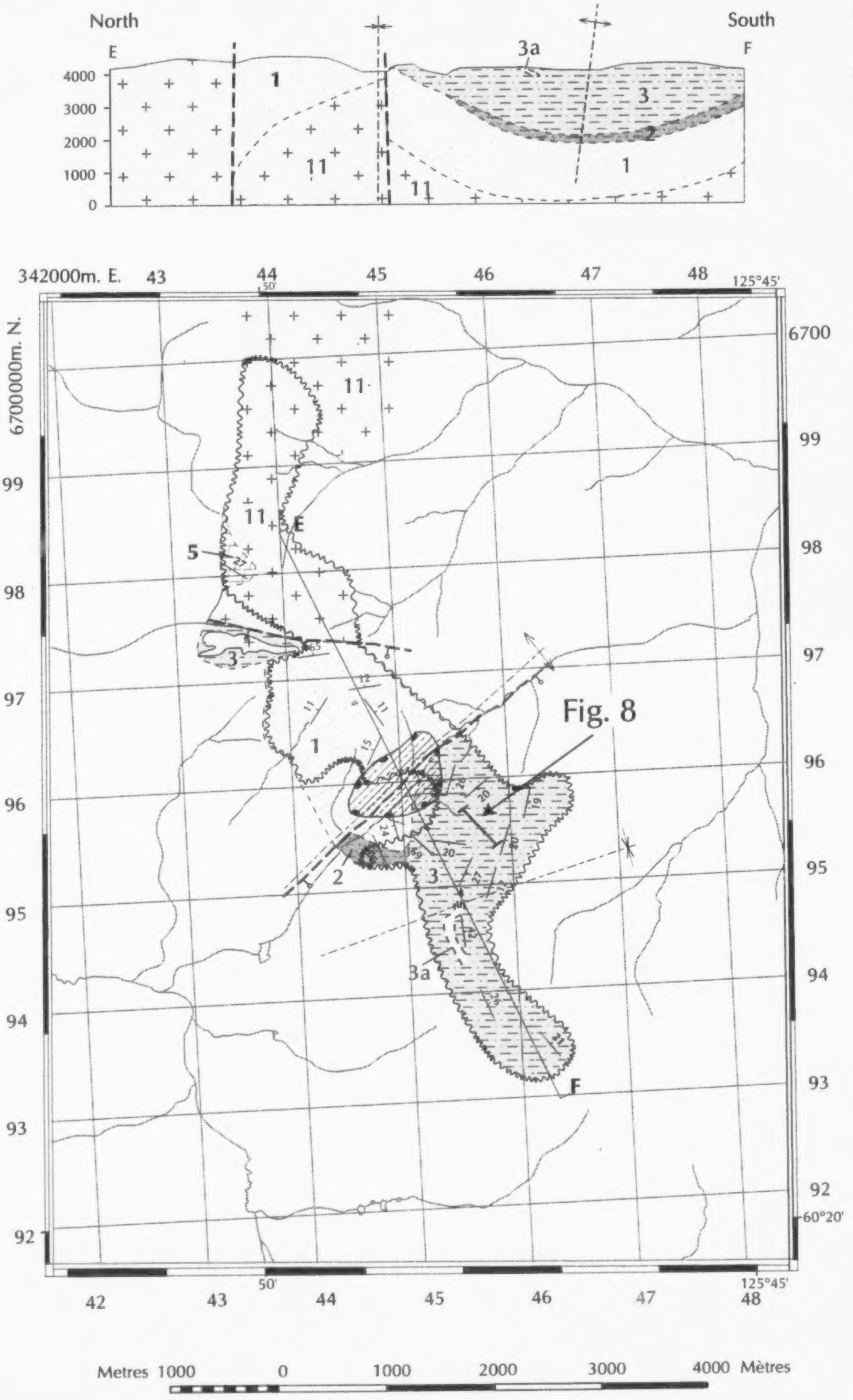

North
South
E
F
4000
3000
2000
1000
0
1
3a
3
2
11
342000m. E.
43
44
45
46
47
48
50'
125°45'
6700000m. N.
6700
99
98
97
96
95
94
93
92
60°20'
42
5
Fig. 8
Metres 1000
0
1000
2000
3000
4000 Mètres

Figure 4. Geologic map with cross-section E-F of South area. Grid spacing is 1 km. For patterns and unit descriptions, see legend from Figure 2.

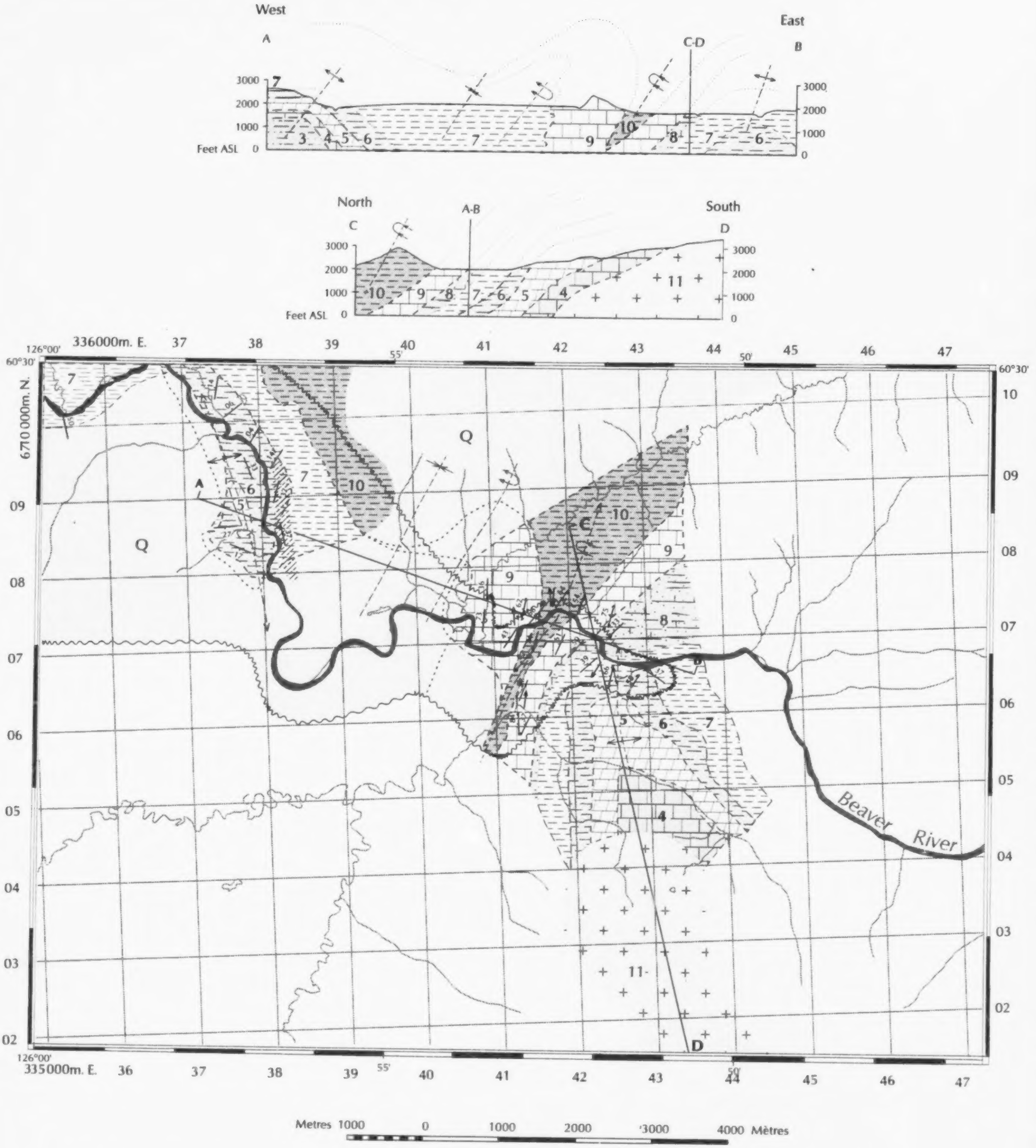

West
East
A
B
C-D
3000
2000
1000
Feet ASL 0
7
3
4
5
6
7
9
10
8
7
6
North
South
C
D
A-B
10
9
8
7
6
5
4
11
126°00'
60°30'
336000m. E.
37
38
39
40
41
42
43
44
45
46
47
55'
50'
6710 000m. N.
10
09
08
07
06
05
04
03
02
Q
Q
7
6
5
10
9
8
4
11
Beaver River
335000m. E.
36
Metres 1000
0
1000
2000
3000
4000 Mètres

Figure 5. Geologic map with cross-sections A-B and C-D of North area. Grid spacing is 1 km. For patterns and unit descriptions, see legend from Figure 2.

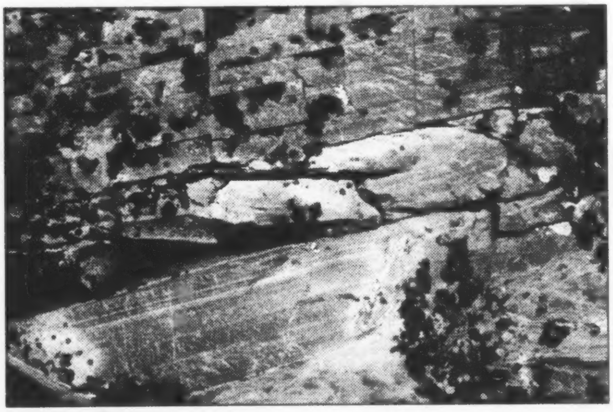


***Figure 6.** Finely laminated quartz sandstone of Unit 1. Pencil in centre of Figure is 14 cm long.*

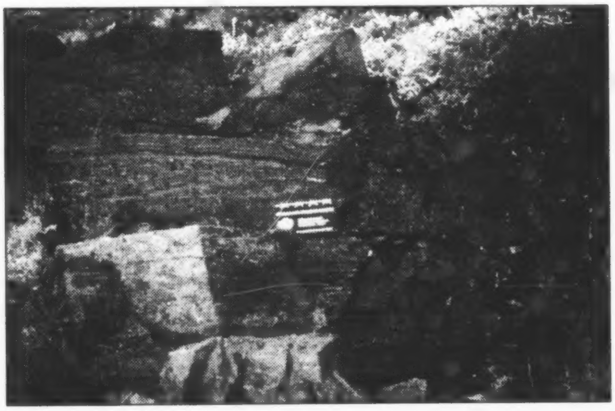


***Figure 7.** Finely laminated, black siltstone and black and dark grey, very fine-grained sandstone of Unit 2. Scale is graduated in centimetres.*

maroon variant has sharp upper and lower contacts with more typical green argillite.

On the ridge immediately south of the syenite intrusion, a unit of thin-banded, fine-grained, calcareous, cream and green or grey calc-silicate rock has been observed. This unit overlies Unit 1 quartz sandstones and is tentatively interpreted as a contact-metamorphosed equivalent of a calcareous interval within this facies association.

Facies Association 2 (sandy argillite) is similar to Facies Association 1, differing mainly in containing a higher percentage (up to 50% or more) of very fine-grained sandstone as very thin to thin beds (locally medium bedded). Minor beds of granule-conglomeratic sandstone are also present. The sandstone beds are sharp- to erosionally based and commonly normally graded (rare beds show inverse grading) with rare parallel lamination or current ripple cross-lamination. Well developed slump horizons up to several metres thick occur locally, as do load casts and convolute bedding.

Facies Association 3 (breccia) is characterized by granule to pebble to (less commonly) cobble breccia. The breccia is poorly sorted and ungraded (Fig. 11), although in rare cases oblate clasts are oriented roughly sub-parallel to bedding. Beds display sharp bases, generally with little (up to 10 cm locally) or no basal relief. Rare examples of upper surface relief (up to 3 cm) have also been recognized. Matrix varies from silty and muddy to sandy, and beds vary from matrix supported to clast supported, more commonly the former. In some beds, clasts are predominantly intraformational, consisting mainly of angular argillite fragments. Other beds contain abundant allochthonous clasts, including volcanic material and microbially laminated carbonate. Some breccia beds were observed to pass laterally into slumped horizons or into successions of argillite cut by intraformational truncation surfaces.

The depositional setting of the green argillite association was in quiet water, as indicated by the fine grain size and lack of high-energy physical structures. The lack of wave-produced structures is consistent with deposition below wave-base. A similar setting prevailed during deposition of the sandy argillite facies, except that the supply of sandy sediment was greater. The sharp-based, normally graded sandstone beds strongly resemble distal tempestites (e.g., Brenchley, 1985).

The prevalence of slumping suggests deposition on a slope (Dalrymple and Narbonne, 1996). This, combined with the common presence of distal tempestites and the absence of wave-formed structures, is consistent with deposition in a slope-shelf transition or uppermost slope setting.

The massive, unsorted character of the breccia beds suggests deposition from debris flows, providing further evidence for a slope setting. The presence of volcanic material in many of the breccias may reflect a tectonically active setting, as may the prevalence of slumping in the succession.

Map Unit 3 corresponds to Unit 1 of Douglas and Norris (1959), which they correlated with the Proterozoic Apekunni Formation of southern Alberta based on lithologic similarity. No body or trace fossils were

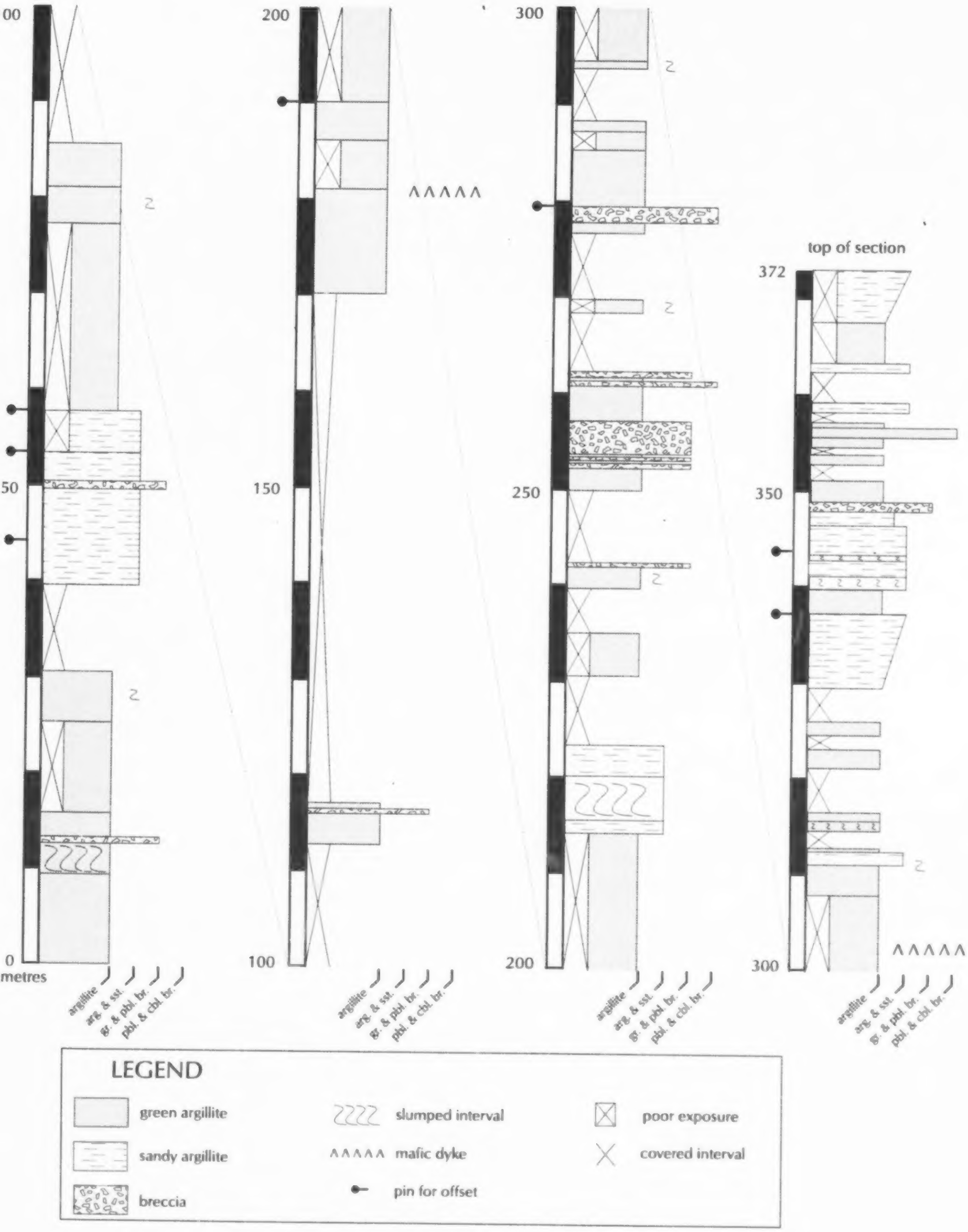

100
50
0
metres
200
150
100
300
250
200
top of section
372
350
300
argillite
arg. & sst.
gr. & pbl. br.
pbl. & cbl. br.
LEGEND
green argillite
sandy argillite
breccia
slumped interval
mafic dyke
pin for offset
poor exposure
covered interval

Figure 8. *Measured stratigraphic section through the best exposed part of Unit 3. Pins to left of stratigraphic column indicate levels at which lack of exposure necessitated an offset of the measured section. Base of section is at coordinates: 345620 E, 6695764 N (UTM NAD83); top of section is at NTS coordinates: 345903 E, 6695412 N (UTM NAD83); arg = argillite; sst = sandstone; gr = granule; pbl = pebble; cbl = cobble; br = breccia.*

observed during the 2000 field season. The correlation of Douglas and Norris (1959) is provisionally adopted, pending further data.

Unit 3a

A distinctive greyish-red, clast-supported, poorly to moderately sorted, crudely bedded conglomerate forms a laterally discontinuous subunit 3(a) about 300 m above the base of Unit 3. Clasts in the conglomerate are subround to subangular, ranging from pebbles to cobbles (Fig. 12). The conglomerate is polymictic with clasts of basalt (75%), pale grey to white vein quartz (5%), carbonate (5%), sandstone, and other unidentified material (15%). The matrix is predominantly greyish-red, very fine-grained, poorly sorted sandstone. The conglomerate can be traced for a strike length of approximately 600 m and ranges up to 20 m in thickness. It does not occur in the area of the measured section, but would project into the section's uppermost part.

The source for the basalt clasts forming Unit 3a has not been identified; observed units in the Pool Creek area do not contain any exposed basalt flows. Regionally, basaltic volcanism in the northern Cordillera occurs during Proterozoic, Cambrian, Ordovician, and Devonian times (Gabrielse and Campbell, 1991; Goodfellow et al., 1995).

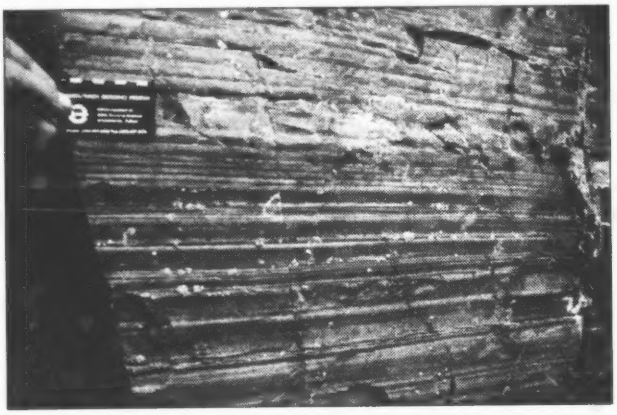


Figure 9. *Greyish-green, banded siltstone with thin, cream, very fine-grained sandstone interbeds from Facies Association 1 of Unit 3. Scale is graduated in centimetres.*

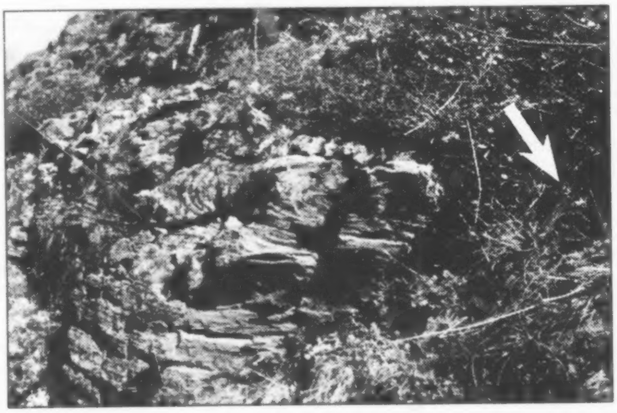


Figure 10. *Isolated sedimentary slump folds in Unit 3. Hammer handle at right of outcrop (at tip of arrow) is approximately 30 cm long.*

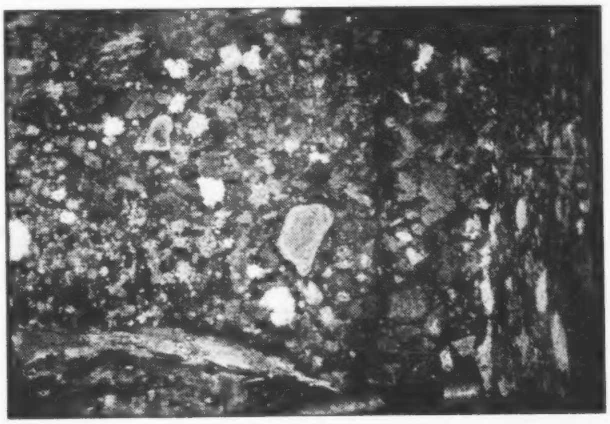


Figure 11. *Thin unit of breccia (Facies Association 3 of Unit 3). Light coloured fuzzy patches are lichen. Hammer head for scale is at bottom of figure.*

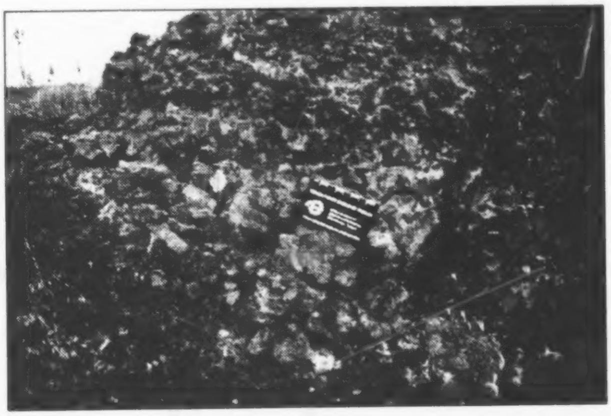


Figure 12. *Discontinuous, clast-supported, greyish-red conglomerate of Unit 3a. Clasts are subround to subangular and predominantly basalt. The matrix ranges from buff, coarse-grained sandstone to very fine-grained, greyish-red sandstone. Scale is graduated in centimetres.*

Unit 4

Unit 4 is exposed on the ridge crest immediately north of the syenite intrusion and consists of a massive, finely crystalline, nonfossiliferous, grey limestone with an interpreted thickness of 70 m. It was not observed during the 2000 field season. The description and thickness are based on earlier mineral exploration property geological mapping on the BEAV claims (Burt, 1983).

The limestone is tentatively correlated with Sunblood Formation (Kingston, 1951) on the basis of stratigraphic position and lithologic similarity. Sunblood Formation ranges from early Whiterockian (early Middle Ordovician) to Kirkfieldian (late Middle Ordovician) in age and is correlative with Haywire Formation of Gordey and Anderson (1993). Both Sunblood and Haywire formations are shallow-marine, platform-carbonate strata with extensive exposures in the Yukon and the Northwest Territories, north and west of the Pool Creek area (Gordey and Makepeace, 1999).

Unit 5

Unit 5 was observed in scattered outcrops along a small stream flowing east into the Beaver River in the North area, and along the southwest margin of the syenite intrusion in the South area. It consists of thinly bedded, tan-weathering, very fine-grained, sucrosic, laminated to massive dolostone (Fig. 13). Individual beds range in thickness from 2 to 50 cm and are slightly undulating. The lowermost exposures contain ovoid black chert nodules up to 15 cm across. The unit's lower contact is unexposed, and the upper contact is conformable with Unit 6. It has an interpreted thickness of 60 m.

Unit 5 is also tentatively correlated with Sunblood Formation on the basis of general stratigraphic position and lithologic similarity. Age, correlations, and depositional environments are as described for Unit 4.

Unit 6

Along the Beaver River, Unit 6 is composed of scattered outcrops and small knobs of sandstone and pebbly grit with lesser interbeds of bioturbated dolomitic siltstone and dark grey shale. It has an aggregate thickness of approximately 200 m. The lower contact is conformable and marked by an abrupt change from dolostone to sandstone. The upper contact is not exposed in the map area but is considered to be conformable.

The predominant lithology is a quartz-rich, noncalcareous, thick-bedded, medium- to coarse-grained, light to dark grey or tan sandstone to pebbly grit (Fig. 14). Beds are thin to thick (2-200 cm), massive and blocky, well indurated, and planar to undulating. Grit intervals are generally 5-100 cm thick. The grit is poorly sorted and contains up to 60-70% rounded, white and bluish quartz pebbles up to 10 mm across. The sandstone is generally fine to coarse grained, sucrosic, with 5-10% rusty to black opaque grains. It typically weathers light grey to brownish-grey with local rusty stain, yellow jarosite coating, or off-white, opaque calcite coating.

The sandstone contains intervals up to 2 m thick of light grey, dolomitic, bioturbated fine sandstone to siltstone

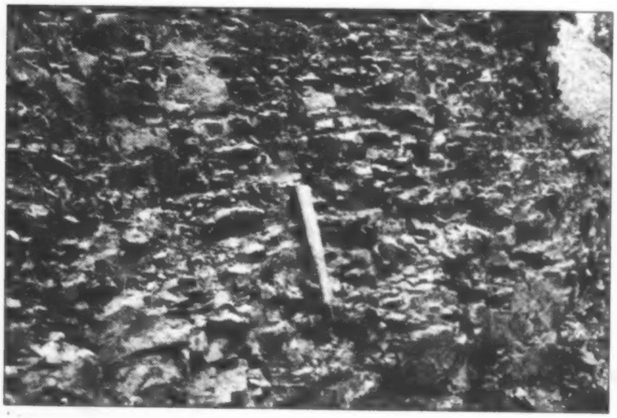


Figure 13. *Thinly bedded, tan-weathering, fine-grained dolostone with black chert nodules up to 5 cm across (Unit 5).*

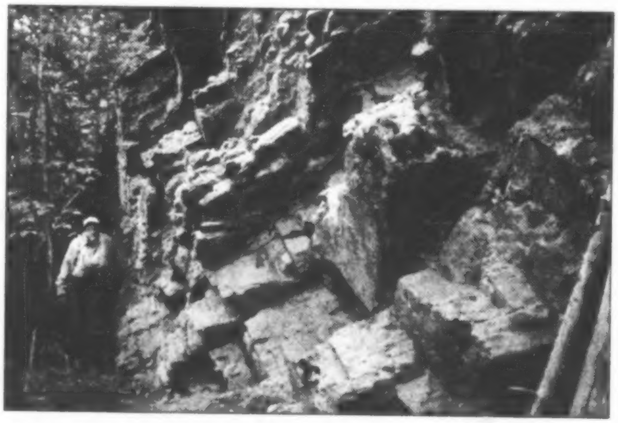


Figure 14. *Quartz-rich, thick-bedded, medium- to coarse-grained sandstone of Unit 6. Beds dip into the figure and extend from upper right to lower left.*

(Fig. 15). These intervals are recessive and contain minor discontinuous, dark grey shaly partings. Dark grey to black, noncalcareous shale forms a third lithotype occurring in minor amounts (less than 20%) as thin beds up to 2 m thick.

Unit 6 is distinctive and constitutes a useful marker horizon. It is considered to be Late Ordovician because it lies conformably between Middle Ordovician Unit 5 (Sunblood Formation) and Ordovician-Silurian Unit 7 (Road River Group). It represents a transitional environment between platform carbonate sedimentation (Unit 5) and euxinic, basinal sedimentation (Unit 7).

Unit 7

Unit 7 forms recessive scree slopes and scattered outcrops along Beaver River in the North area. It consists of interbedded black, locally calcareous, silty shale and siltstone, black bedded chert, and black, laminated, argillaceous limestone, and has an interpreted thickness of approximately 500 m (Fig. 16). The different lithologies of Unit 7 are interbedded on a scale of metres to tens of metres.

The siltstone and shale are thinly bedded (2-20 mm), platy, weather light to medium grey, and locally have yellow jarositic or white coatings. Bedded cherts consist of 5- to 10-cm, parallel laminated chert beds with 1-3 cm shaly interbeds. Limestone is dark grey with thin light grey interbands. Locally the chert, siltstone, and shale contain tan-weathering dolostone nodules. Sandstone is very fine-grained, medium grey, finely micaceous, and finely laminated. Straight and spiral graptolites occur on bedding planes throughout the unit. Other macrofossils include crinoid columns and rare brachiopods.

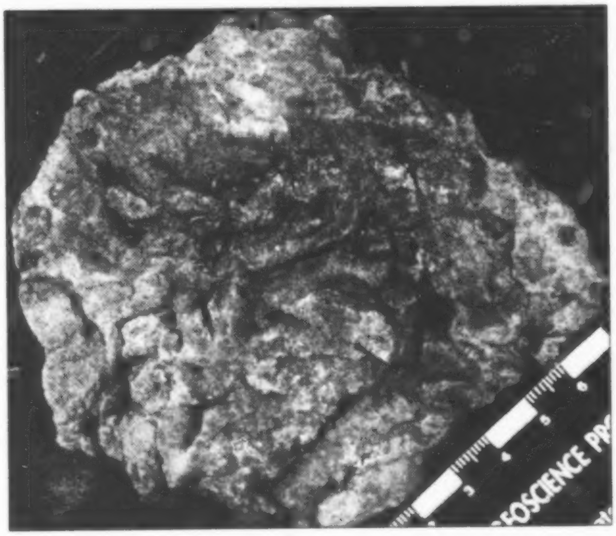


Figure 15. *Close-up of bedding plane surface of bioturbated, dolomitic, very fine-grained sandstone to siltstone. Burrows are randomly oriented on the bedding plane surface. Scale is graduated in centimetres.*

Lower and upper contacts are not exposed. Unit 6 consistently underlies Unit 7, suggesting a conformable lower contact. Immediately south of Beaver River, Unit 7 is conformably overlain by Unit 8. In the northernmost part of the map area, Unit 7 is directly overlain by Unit 10. This contact between units 7 and 10 will be discussed further in the section describing Unit 10.

Unit 7 is correlated with Lower Cambrian to Lower Devonian Road River Formation in the Richardson Mountains (Jackson and Lenz, 1962). Similar Ordovician-Silurian graptolitic shales are present in several areas in Selwyn Basin leading Gabrielse et al. (1973) to suggest the name Road River Formation be extended to all these shales. Gordey and Anderson (1993) raised Road River to group status because two formations can be recognized within it in the Nahanni area. In Flat River and Glacier Lake map areas, Road River Formation ranges from Caradocian (late Middle Ordovician) to Early Devonian in age. Regionally upper and lower contacts are diachronous. The depositional environment is a relatively deep, euxinic, quiet basin. Bedded cherts are probably biogenic, forming from radiolarian detritus.

Unit 8

Unit 8 outcrops along Beaver River immediately north of the syenite intrusion. It consists of interbedded, buff-

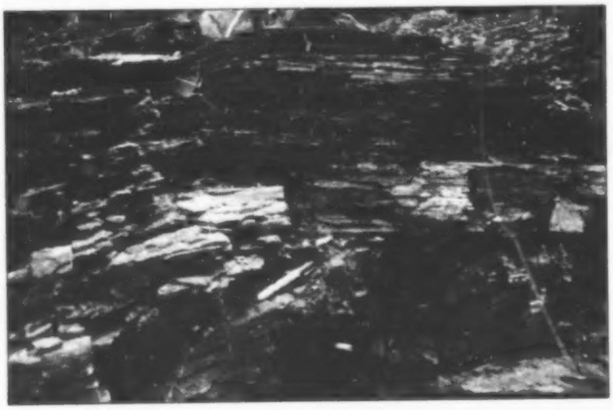


Figure 16. *Black, thinly bedded, silty shale of Unit 7 (Road River Group). Pen in centre of Figure is 13 cm long.*

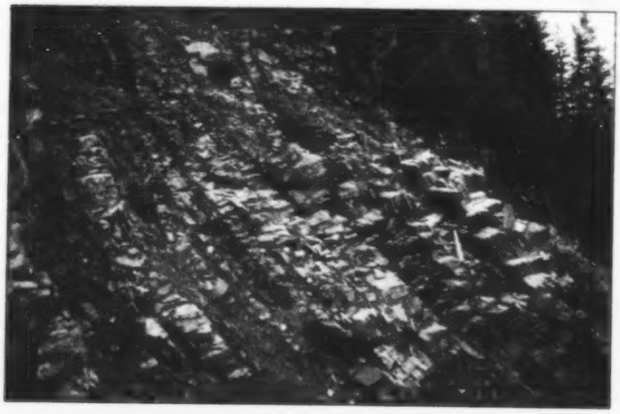


Figure 17. Buff-weathering, platy, siltstone, very fine-grained sandstone and dark grey, fissile shale of Unit 8. Hammer for scale in right centre of figure.

weathering, dolomitic, micaceous, platy siltstone and very fine-grained sandstone, alternating with dark grey, fissile, silty shale (Fig. 17). Black chert and resistant, lensoidal, dolomitic sandstone also occur in minor amounts. The interbedded siltstone and sandstone are finely planar parallel laminated, with beds of 5 to 20 mm thickness occurring in intervals up to 4 m thick. Lensoidal sandstone occurs in beds up to 50 cm thick and contains crinoids and other broken fossil debris. The silty shale is medium to dark grey, noncalcareous, gritty, and finely micaceous. It typically grades upward to buff siltstone.

Slightly further east (just outside the mapped area), Unit 8 becomes a massive dolostone (Burt, 1983). The unit's thickness increases from 100 to 600 m from west to east. The unit is absent in the extreme northwest corner of the map area. Upper and lower contacts are not exposed but are tentatively interpreted as conformable. The occurrence of micaceous clastic sediments and rapid thickening toward the east into a massive dolostone suggests this unit represents a succession of clastic debris sediments deposited westward off a shallow carbonate platform margin. The age of Unit 8 is broadly constrained to be Silurian-Devonian by its position above Ordovician-Silurian Unit 7 and below Middle Devonian Unit 9.

Unit 9

Unit 9 forms cliff outcrops in the central part of the North area, but is absent in the northwest corner of the map area. It consists dominantly of dark grey to black, medium- to thick-bedded, argillaceous limestone with thin dark grey shale or light grey siltstone interbeds (Fig. 18). The uppermost 20 m of the unit is more resistant and forms steep cliff outcrops. The maximum thickness of Unit 9 is approximately 600 m, thinning to the east in conjunction with the thickening of Unit 8. The lower contact is conformable and is marked by the first appearance of abundant, medium-bedded limestone. The upper contact is marked by a sharp transition to the fine-grained, siliceous shale of Unit 10. The absence of Unit 9 in the northwest corner of the map area suggests that the upper contact is unconformable.

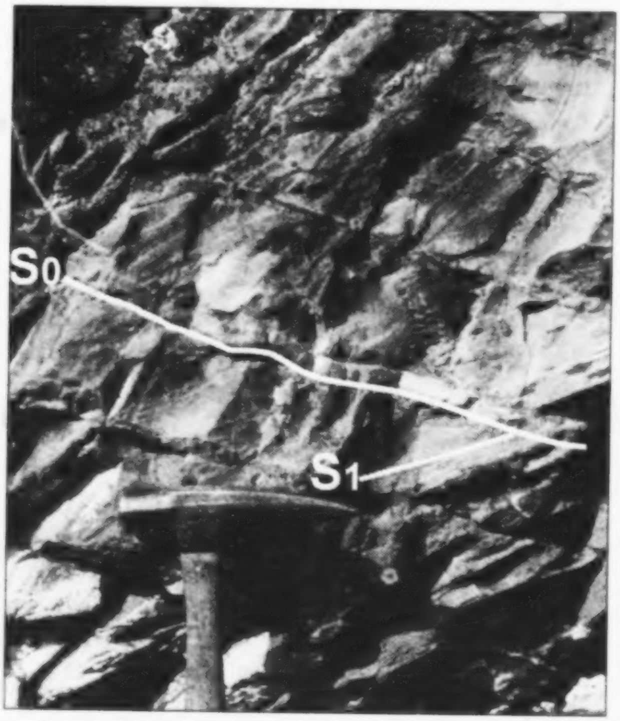


***Figure 18.** Looking north at thin- to medium-bedded, dark grey, micritic, argillaceous limestone of Unit 9. S_0 bedding dips gently from left to right, and S_1 slaty cleavage dips gently from right to left.*

Limestone beds are 10-50 cm thick with shaly partings (Fig. 18). Locally, the limestone beds contain thin black chert nodules or black chert beds. Generally, the limestone is micritic; sparse grainstones up to 10 cm thick contain fossil debris crinoid columns with single and twin axial canals. The resistant limestone at the top of the unit contains undulatory beds 2-150 cm thick with platy to fissile, recessive, medium to dark grey, calcareous shale and siltstone with minor 30- to 40-cm-thick sandstone interbeds. The shale interbeds are parallel laminated on a millimetre scale.

The presence of crinoid columns with twin axial canals constrains Unit 9 within upper Lower Devonian to upper Middle Devonian age (Dunn and Kendall, 1978). The argillaceous nature of the limestone and its rhythmic bedding indicate a quiet water, offshelf depositional environment.

Unit 10

Unit 10 occurs as cliff outcrops along streams and as scree slopes on ridges in the North area. It consists of black silty shale interbedded with black bedded chert. In the northwest corner of the North area, it overlies Unit 7, and in the north central part of the North area, it rests on Unit 9. The upper contact is not observed in the map area. The minimum estimated thickness for Unit 10 is 200 m.

The silty shale is platy to thinly bedded (2-10 mm thick), noncalcareous, siliceous, and typically subcrops as bluish-grey- to light brownish-grey-weathering scree slopes (Fig. 19). Fresh surfaces are greyish-black with faint, medium grey, parallel planar laminae. The black bedded chert interbeds consist of 2-10 cm chert beds separated by shaly partings. Silty shale and chert are interbedded on a scale of metres to tens of metres with proportions of the two lithologies varying widely between outcrops. Large, dark grey limestone concretions up to 2 m across were observed within the siliceous shale in the lowermost part of Unit 10. Greyish-black, light to medium grey weathering, blocky, micritic limestone occurs as a minor lithology within this unit.

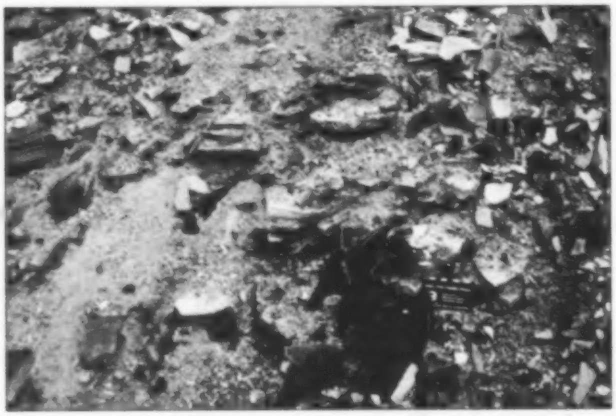


Figure 19. *Thin-bedded, siliceous, silty shale of Unit 10. Scale is graduated in centimetres.*

Unit 10 is correlated with Devonian-Mississippian Earn Group (Gordey et al., 1982) and Besa River Formation (Kidd, 1963). The pale grey- to white-weathering colour is characteristic for Earn Group. Exposures in Pool Creek area however, do not contain the chert-pebble conglomerates typical of Earn Group within Selwyn Basin strata farther to the northwest. Straight cephalopod (?) fossils of unknown age were observed in Unit 10 in the map area. At least a part of the unit is constrained to be younger than Middle Devonian because it overlies the Middle Devonian Unit 9. The lower contact is interpreted as being an unconformity since Unit 10 overlies Unit 9 in the central part of the North area, and Unit 7 in the northwest part of the North area.

Abundant black shale and black bedded chert denote a deep water, euxinic, basinal depositional setting. The presence of carbonate nodules indicates water depths do not reach the calcite compensation level. Cherts are inferred to be biogenic even though radiolarians are not readily visible in hand sample.

IGNEOUS ACTIVITY

Unit 11 (Pool Creek Syenite)

The map area is intruded by a north-trending, unfoliated syenite (Unit 11) consisting of medium to coarsely crystalline, randomly oriented, pink potassium-feldspar, with lesser dark green hornblende. Unit 11 is exposed for a strike length of 7 km along the one ridge above tree line and has informally been called the Pool Creek syenite (Harrison, 1982). Syenite dykes and sills occur in country rocks immediately adjacent to the intrusion. Linear, intensely clay-altered zones within the syenite weather to soft, white scree slopes. These zones are typically 3-5 m wide and can extend for tens of metres.

An isolated intrusive plug of similar composition immediately north of the Pool Creek map area has an average K-Ar date on three biotite separates of 53.1 ± 1.8 Ma (Harrison, 1982; Stevens et al., 1982), corresponding to an early Eocene age.

Basalt

Thin, dark green, fine-grained to aphanitic, noncalcareous basaltic dykes up to one metre in width crosscut the syenite intrusion and Unit 3. Marginal contacts of the dykes are sharp. The dykes are not mappable at 1:50 000 scale.

STRUCTURE AND METAMORPHISM

In the North area, sedimentary units are deformed into tight to slightly overturned, east-verging, north-plunging folds (see cross-section AB in Figure 5). Hinge zones of the folds contain a well developed, axial planar, slaty cleavage, which dips moderately northwestward at approximately 55° with an average strike of 240°. Measured fold axes have an average trend and plunge of 007/14.

The maximum age of deformation in the North area is post-Carboniferous because Unit 10 is deformed. The minimum age of deformation is pre-Eocene because the Pool Creek syenite is unfoliated and therefore post-tectonic.

In contrast to the structural style in the North area, primary sedimentary bedding in the South area is warped into broad, open, sub-horizontal, northeast-trending folds (see cross-section EF in Figure 4) with no associated cleavage development. The mapped anticline in the South area has a northeast-trending, steep normal fault in the hinge zone, suggesting brittle faulting slightly post-dates folding.

Douglas (1976) inferred a westward-verging thrust (Beaver River Thrust) that emplaced Proterozoic strata above the

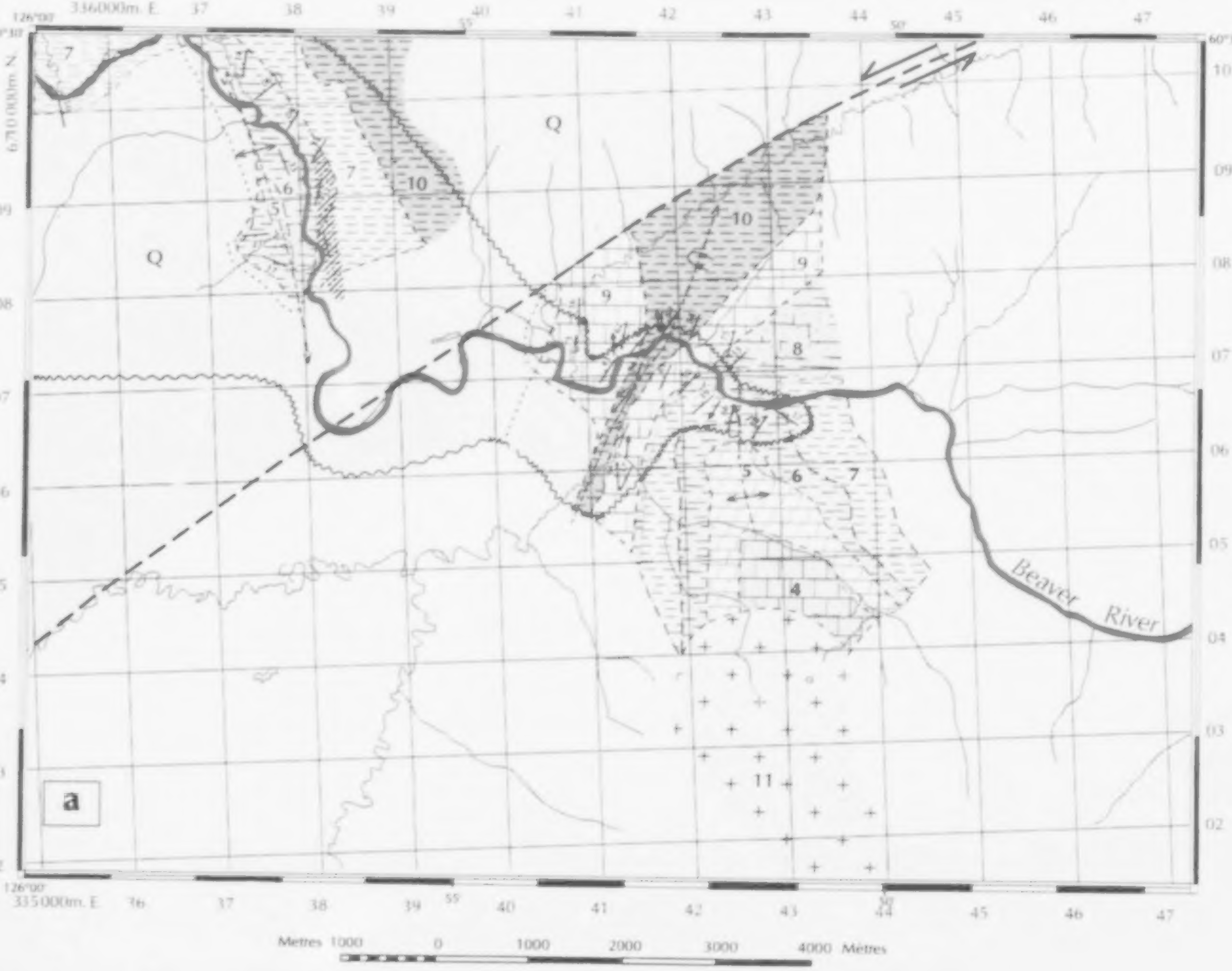

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Figure 20. *Two possible structural interpretations for sinistral offset of lower contact of Unit 10 in the North area. (a) Lower contact offset approximately 2 km by northeast-trending fault. (b) Lower contact offset approximately 2 km by northward-trending anticline-syncline fold couplet. Grid spacing is 1 km. For unit descriptions, see legend from Figure 2.*

Paleozoic Mattson and Besa River formations in the South area. Strata in the South area previously mapped as Mattson and Besa River formations (Units 1 and 2 in this report) differ markedly from these units and have probably been misidentified. Units 1 and 2 occur stratigraphically below Unit 3 without structural interruption and are probably of Proterozoic age. The Beaver River Thrust is not needed to explain the distribution of units within the map area.

Skarn, gossan, and biotite hornfels comprise the contact metamorphic aureole of the main syenite body and the syenite dykes and sills in the South area. The spatial association of the aureoles with northeast-trending faults suggests that intrusion of the syenite and contact metamorphism of the sedimentary units was broadly coeval with the development of the northeast-trending folds and faults. Therefore, the open folds in the South area are tentatively considered to be Eocene.

Minor calcareous members within Unit 3 contain metamorphic garnet, epidote and chlorite forming an extensive, poorly defined metamorphic halo broadly associated with the Pool Creek syenite intrusion. Tremolite has also been tentatively identified in carbonate clasts collected from breccia beds high in Unit 3. Metamorphism in the South area may have reached higher temperatures than is readily apparent from hand sample and outcrop inspection.

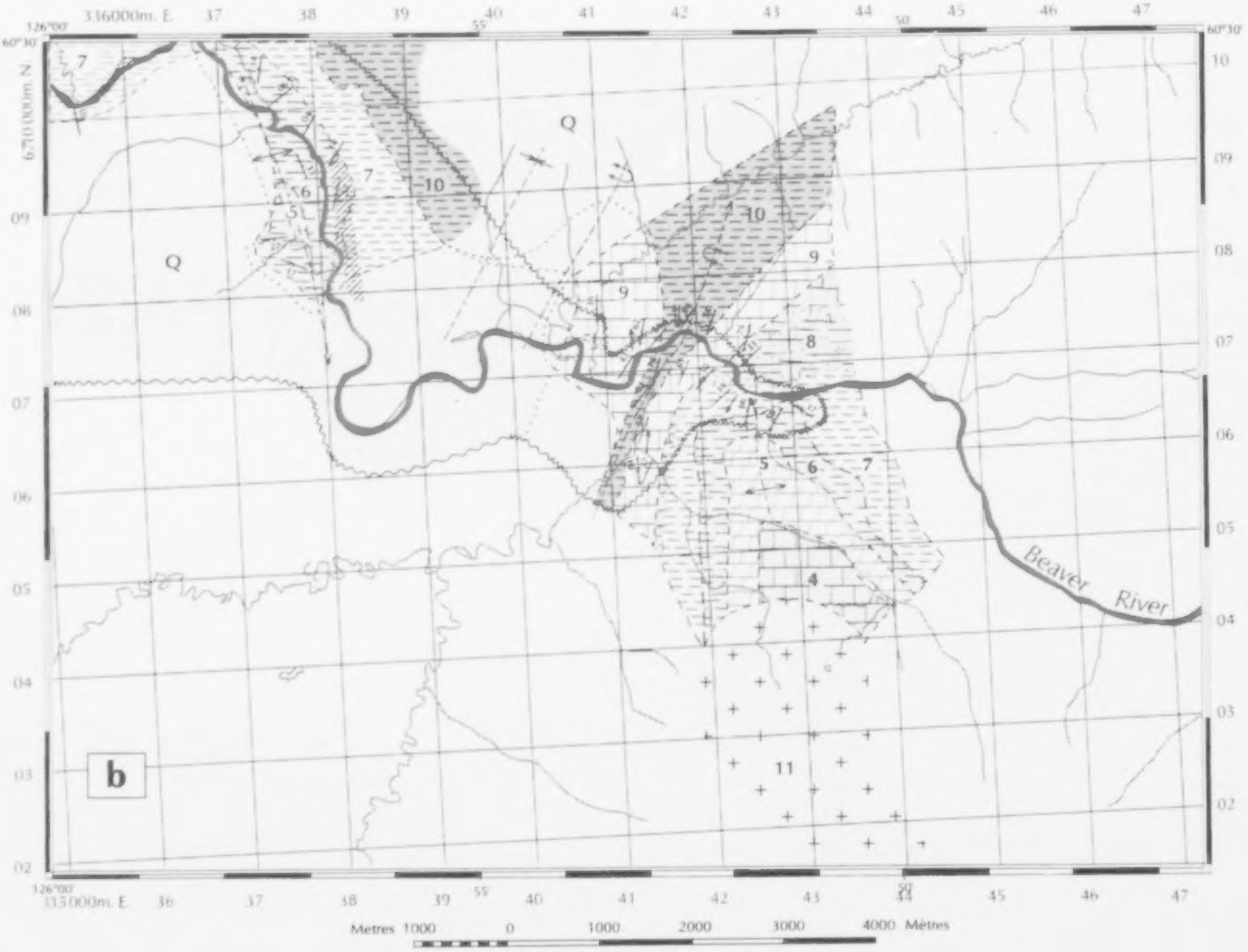
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Figure 20. continued

BEAVER RIVER STRUCTURE

Morrow and Miles (2000) proposed the existence of the Beaver River structure, a major, northeast-trending, crustal, dextral strike-slip fault with 10-20 km of offset during Laramide deformation. They considered the Beaver Fault (mapped by Douglas, 1976) as being the surface expression of this structure. Additional evidence for the Beaver River structure includes deflections of Laramide fold structures and terminations to trends in the residual total field magnetic and Bouger gravity anomaly geophysical maps.

The Beaver Fault, as interpreted by Douglas (1976), trends northeast through the North area in the northwest corner of the Pool Creek map sheet. Our detailed mapping during the 2000 field season traces stratigraphy and fold structures continuously north-south across the previously mapped location of the Beaver Fault. Although exposure in this area is limited, there is no possibility for a strike-slip fault with 10-20 km of dextral displacement occurring in post-Ordovician time in this portion of the Pool Creek map sheet. Figure 20 compares two possible structural interpretations for the North area. In Figure 20a, a northeast-trending fault with approximately two kilometres of sinistral displacement of the lower contact of Unit 10 is interpreted. In contrast, Figure 20b interprets the apparent sinistral displacement of the lower Unit 10 contact as being caused by a north-plunging, anticline-syncline fold pair. The interpretation presented in Figure 20b is preferred.

ECONOMIC POTENTIAL

Previous mineral exploration in the Pool Creek map sheet identified uranium, thorium, and REE prospects in the syenite intrusion and associated dykes, and in the contact aureole (Yukon MINFILE, 1997). Surface showings were pod shaped and could not be traced laterally or downdip.

During the 2000 field season, gamma ray scintillometry surveys (total counts and potassium counts) were completed over some of the earlier identified prospects (A. Fonseca, pers. comm., 2000). These new surveys indicate that zones of high gamma ray radiation are limited to the syenite pluton and associated dykes. Skarns do not contain greatly anomalous gamma ray counts.

In the North area, previous mineral exploration focused on identifying and evaluating base metal sedimentary-exhalative (SEDEX) targets (Yukon MINFILE, 1997). The northwest corner of the map sheet contains a large ferricrete gossan immediately east of the Beaver River with anomalous values for zinc, cobalt, and nickel (Cathro, 1983). No tightly constrained source for the ferricrete gossan has been identified.

Areas of the Yukon to the northwest contain significant stratiform zinc-lead-silver-barite deposits in Earn Group and Road River Group strata (Abbott et al., 1986). Geological mapping during the 2000 field season confirmed that the North area contains appropriate stratigraphy for SEDEX targets. Previous exploration work in the Pool Creek area has not fully evaluated and tested this suitable stratigraphy. Although no prospects or showings were identified during fieldwork, exploration potential remains for areas underlain by Units 7 and 10.

Dark grey to black, very fine-grained siliciclastic strata were sampled from various units in the Pool Creek map sheet to determine their thermal maturation. Thermal Alteration Indices (TAI) assessed from spore colouration indicated values of 5 or greater, correlative with a vitrinite reflectance value of at least 4.0%R_0 (Utting, 2000). Hydrocarbon potential (oil and gas) is therefore unlikely in the western portion of the map area because the rocks have been thermally altered beyond the gas window (low grade metamorphic rocks).

SUMMARY

Fieldwork in the Pool Creek map sheet during the summer 2000 distinguished North and South areas with distinct stratigraphy and structural deformation histories. The South area stratigraphy consists dominantly of quartz-rich clastic sedimentary rocks of uncertain age (Proterozoic ?). Deformation in the South area is characterized by broad, northeast-trending, sub-horizontal folds.

In contrast, the North area stratigraphy consists of carbonates with interbedded sandstone, siltstone, and shale. The stratigraphic succession ranges in age from Ordovician to Mississippian. Major shale units in the sequence are correlated with Road River Group and Earn Group. Sedimentary units in the North area have been deformed into tight to overturned, north-plunging, east-verging folds. Hinge zones of the folds contain a well developed, axial planar, slaty cleavage.

North and South areas have been intruded by a north-trending, coarsely crystalline, unfoliated, potassium-feldspar-hornblende syenite. K-Ar dating of biotite separates from a similar intrusive plug immediately north of the Pool Creek area results in an early Eocene date

(53.1 ± 1.8 Ma). Small dykes and sills of syenite extend into the country rock in the immediate vicinity of the main syenite intrusion.

Contact metamorphic effects related to the syenite intrusion and associated dykes and sills include biotite hornfels, calc-silicate rock, and gossan. Contact metamorphism appears to be associated with northeast-trending folds and faults of the South area, and is later than the pervasive folding in the North area. North area folding is therefore post-Mississippian and pre-Eocene. Broad northeast-trending folding and metamorphism is early Eocene.

ACKNOWLEDGEMENTS

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Surficial geology and till geochemistry of Weasel Lake map area (105G/13), east-central Yukon

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Bond, J.D., 2001. Surficial geology and till geochemistry of Weasel Lake map area (105G/13), east-central Yukon. *In:* Yukon Exploration and Geology 2000, D.S. Emond and L.H. Weston (eds.), Exploration and Geological Services Division, Yukon, Indian and Northern Affairs Canada, p. 73-96.

ABSTRACT

Weasel Lake map area (105G/13) is located at the northwestern end of the Finlayson Lake belt (displaced Yukon-Tanana Terrane) and extends northward into ancient North American rocks. Several volcanogenic massive sulphide deposits including: Wolverine, Kudz Ze Kayah, Fyre Lake and the Ice, have been discovered in this part of Yukon-Tanana Terrane, which makes this region one of the most prospective areas of Yukon. Limited outcrop exposure, due to widespread Quaternary cover, has made prospecting challenging in many parts of this terrane, including Weasel Lake map area. Surficial geological mapping and till geochemical sampling was conducted in the map area to better understand its mineral potential. Ice-flow over the area trended at approximately 305° and remained topographically unobstructed through the last glacial maximum. As a result, basal till was deposited across most of the map area. Late glacial deposition of glaciofluvial sediment and meltout till was more common in the northeast part of the map and along the Pelly River. Results of the till geochemical sampling program highlighted anomalies in base-metal elements, platinum/palladium indicators, as well as a gold indicator suite, suggestive of epithermal mineralization.

RÉSUMÉ

La région de Weasel Lake (105G/13) se trouve à l'extrémité nord-ouest de la ceinture de Finlayson Lake (terrane de Yukon-Tanana exotique) et s'étend vers le nord dans des roches de l'Amérique du Nord ancienne. Plusieurs gîtes de sulfures massifs volcanogènes, comprenant les gisements Wolverine, Kudz Ze Kayah, Fyre Lake et Ice, ont été découverts dans cette partie du terrane de Yukon-Tanana, ce qui fait de cette région l'une des plus prometteuses du Yukon. Les affleurements limités, en raison d'une couverture étendue de dépôts quaternaires, ont compliqué la prospection dans de nombreuses parties de ce terrane, y compris la région de Weasel Lake. La cartographie géologique des dépôts superficiels et l'échantillonnage géochimique des tills ont été réalisés dans la région afin de mieux comprendre son potentiel minéral. L'écoulement glaciaire sur la région avait une orientation d'environ 305°, sans rencontrer d'obstacle topographique tout au long du dernier pléniglaciaire. Par conséquent, un till de fond s'est déposé sur la majeure partie de la région. Un dépôt tardiglaciaire de sédiments fluvio-glaciaires et d'un till de fusion était plus commun dans la partie nord-est de la carte et le long de la rivière Pelly. Les résultats du programme d'échantillonnage géochimique des tills ont mis en lumière des anomalies dans les métaux communs, les minéraux indicateurs de platine/palladium, de même que dans un cortège indicateur d'or, évoquant une minéralisation d'origine épithermale.

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INTRODUCTION

This paper provides the initial results for a till geochemistry and surficial geological mapping program in Weasel Lake map area (105G/13; Fig. 1). On-going exploration for base metals in the Finlayson Lake district has focused in areas of well exposed uplands and in drift covered lowlands. Large tracts of the northern part of Finlayson Lake map area are covered by glacial drift, which has less than ten percent bedrock exposure. An important tool for regional exploration in the Finlayson district has been the regional stream sediment geochemical database (RGS, Hornebrook and Friske, 1988). This database contributed to the discovery of the Wolverine deposit by revealing an anomalous zinc value in stream sediments. However, in areas of low relief, the concentration of streams is lower and many of the drainages have insufficient energy to erode through the glacial sediment cover to bedrock. Therefore, the RGS data is more sparse and somewhat diluted compared to data derived from the surrounding mountainous terrain (Fig. 2). The integration of till geochemical sampling and surficial geology provides geoscience information that is an alternative to the RGS data.

The 2000 surficial geology and till geochemistry sampling program aimed to define the mineral potential of the northwestern part of the Finlayson Lake map area (105G/13). This project is centred on the northwestern part of the displaced portion of Yukon-Tanana Terrane and straddles the Finlayson Lake fault zone into ancient North American rocks.

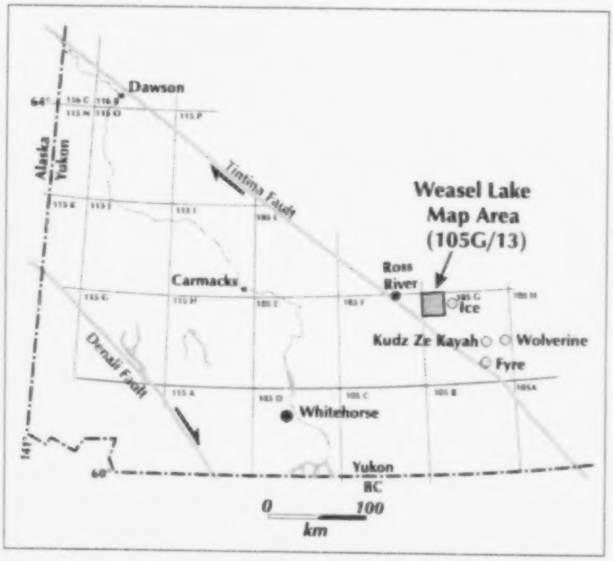


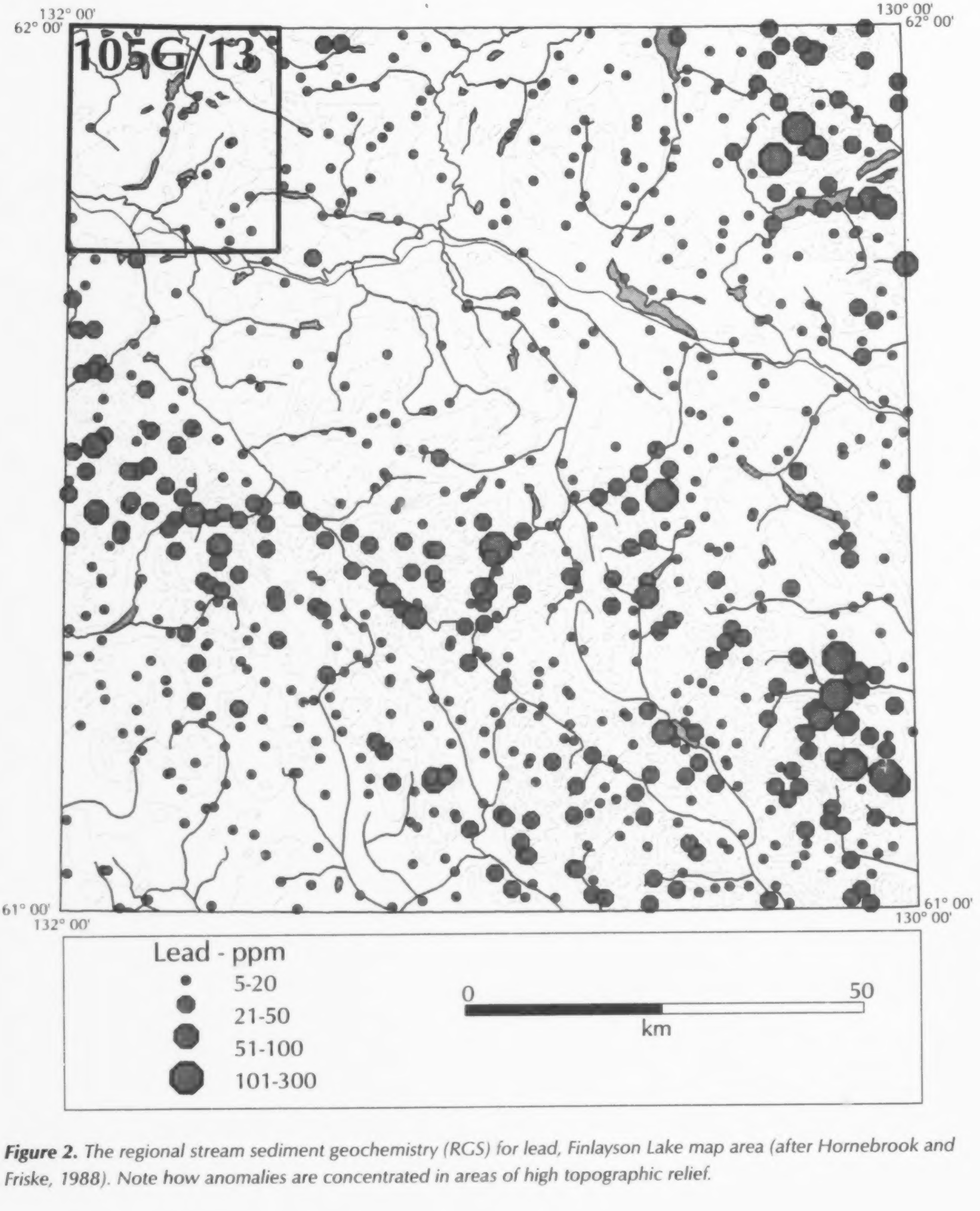
Figure 1. Location of Weasel Lake map area. Local mineral deposits in Finlayson Lake map area (105G) are also indicated.

PHYSIOGRAPHY AND GEOLOGIC SETTING

Weasel Lake map area is located in east-central Yukon, approximately 40 km east of Ross River (Fig. 1). The area lies within the Yukon plateau and is bound by the Pelly River and the Robert Campbell highway along the southern border. Low to moderate relief characterizes the map area (Fig. 3). Many drainages within the study area are internally drained, creating numerous small lakes. Drainages that exit the map area either flow north into the Ross River or south into the Pelly River. Local plateaus rise as much as 210 m above the lakes and in most places not more than 90 m. Highlands along the eastern border of the map rise 600 m above the lowlands, reaching a maximum elevation of 1685 m above sea level.

SOIL, VEGETATION AND PERMAFROST

Vegetation changes are a reflection of soil moisture conditions created by micro-topographic changes and surficial geology. Most low plateaus and valley bottoms consist of mixed white and black spruce with an understorey of willow and dwarf birch. Moisture traps are created in local depressions and are characterized by poor soil development, moss accumulations, black spruce, willow and a high permafrost table. Low relief landforms are better drained and typically have dry soils, well developed soil horizons, a low permafrost table, thin moss mats, white spruce, aspen and minor grass cover. Large, poorly drained areas blanket the inter-plateau valleys, especially in the southern two-thirds of the map area, and occur locally near many of the lakes. These areas have low-density black spruce forests with thick sphagnum accumulations, tussocks, willow, and commonly have standing water. South and southeast facing slopes are dominated by well drained soils, no permafrost, grasslands, aspen and varieties of shrubs. Numerous ages of fire-kill forests are present. The soil moisture conditions usually decrease in these areas due to the decreased insolation cover that results with the loss of spruce trees. This also results in a lower permafrost table for these areas.


132° 00'
62° 00'
130° 00'
62° 00'
105G/13
61° 00'
132° 00'
61° 00'
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Lead - ppm
● 5-20
● 21-50
● 51-100
● 101-300
0
50
km

Figure 2. *The regional stream sediment geochemistry (RGS) for lead, Finlayson Lake map area (after Hornebrook and Friske, 1988). Note how anomalies are concentrated in areas of high topographic relief.*

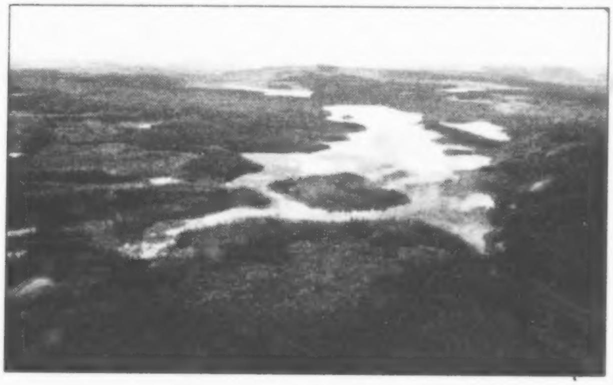


Figure 3. *The physiography of Weasel Lake map area, as shown in the above aerial photo, is characterized by low relief, numerous lakes and poor drainage.*

GEOLOGIC SETTING

Regional

Weasel Lake map area is located at the northwestern end of the displaced portion of Yukon-Tanana Terrane. Yukon-Tanana Terrane in the map area consists of Devonian/Mississippian quartzite and micaceous schist in contact with Carboniferous and Permian basalt, diorite, gabbro, greenstone, argillite and minor serpentinite (Fig. 4; Gordey and Makepeace, 1999). The outcropping serpentinite had not previously been mapped and can be found at the following UTM coordinates: 350200E 6863900N. The Finlayson Lake fault zone separates *in situ* Cassiar platform rocks from Yukon-Tanana Terrane (Fig. 4). Rocks north of the fault zone are poorly exposed. The most prevalent outcrops consist of lower Tertiary mafic basalt flows, necks and dykes (Fig. 5). Graphitic bedrock and a conglomerate unit were noted in the northwest corner of the map area in a region of undocumented geology.

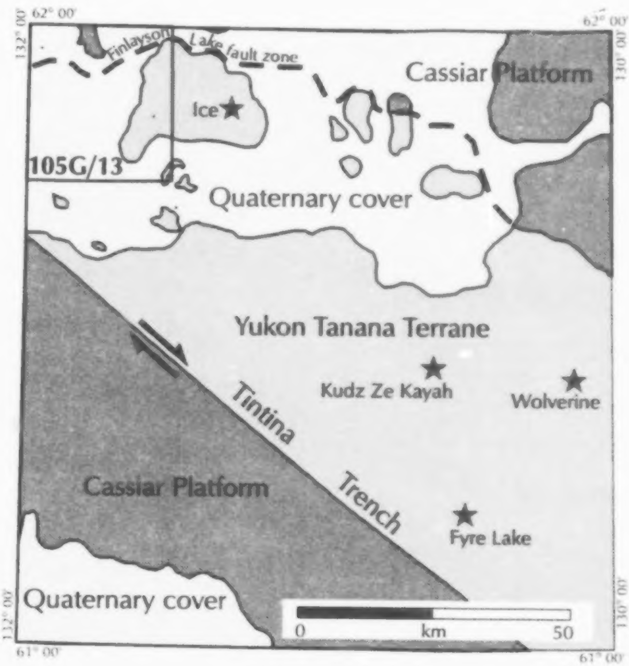


Figure 4. *Geologic terranes of Finlayson Lake map area. Much of Weasel Lake map area consists of Yukon-Tanana Terrane. The northern third consists of Cassiar Platform or the ancient North American continental margin.*

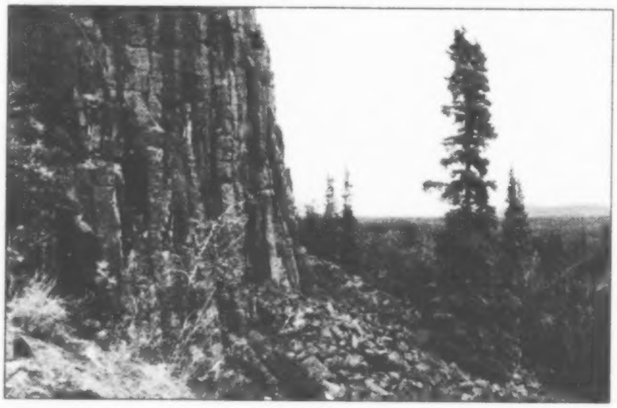


Figure 5. *Some of the youngest geologic units consist of Tertiary volcanic rocks in the north-central part of the map area. The cliff in this photo is approximately 15 m high.*

Deposits

The Ice deposit (Fig. 1) is located 15 km east of Weasel Lake map area in igneous and sedimentary rocks of the Campbell Range belt. The deposit is categorized as a Cyprus-Besshi-style volcanogenic massive sulphide (VMS) deposit with a resource calculation of 4.5 million tonnes grading at 1.48% copper with minor gold, silver and cobalt (Fonseca, pers. comm., 2000).

MINFILE occurrences

Four mineral occurrences are located in Weasel Lake map area (105G 049, 050, 051 and 111; Yukon MINFILE, 1997). Drilling was conducted on the Dot property in 1977 (105G 051; Yukon MINFILE, 1997). The prospect was initially staked after mineralized float was found near a small diorite body. It is considered to be a VMS target.

Limited results have been reported from the remaining three prospects and are categorized as unknown occurrence types.

Mineral occurrences in the surrounding map areas include the Dol, Reno, Fault, Fred and Addison prospects immediately to the east of Weasel Lake map area and south of the Ice deposit (Yukon MINFILE, 1997). These are presumed to be VMS and sedimentary-exhalative (SEDEX) style occurrences located from aeromagnetic anomalies or by identifying mineralized float. To the north of Weasel Lake map area is the Bojo occurrence (105J 028; Yukon MINFILE, 1997), which is located in Selwyn Basin. These claims were staked based on airborne EM-magnetic anomalies and were projected to cover Anvil-type stratigraphy (Yukon MINFILE, 1997). To the west of Weasel Lake map area is the Bruce Lake occurrence (105F 050). Bruce Lake is considered to be an ultramafic-related prospect with its major commodities being Cu, Au and Ag (Yukon MINFILE, 1997). South of Weasel Lake map area is the Eldorado showing (105G 048), which is an ultramafic-related asbestos occurrence (Yukon MINFILE, 1997). The prospect was found by identifying mineralized float in an area of 12 m of overburden.

SURFICIAL GEOLOGY

The surficial geology component of the study consisted of terrain mapping at 1:50 000 scale. Examination of pre-existing surficial geology maps (Jackson, 1994) of the Pelly River area, provided the initial background for this larger-scale mapping program. Air photos at a scale of 1:40 000 were used in the map generation.

Six types of surficial deposit associations were observed in the map area including: organics, alluvium, colluvium, glaciolacustrine, glaciofluvial and glacial deposits (till). Bedrock accounted for less than ten percent of the total map area. General observations indicate that basal till is most widely distributed, whereas glaciofluvial and alluvial deposits occupy some valley bottoms and are particularly common in the northeast part of the map area. Colluvium is more common along the eastern border of the map, where the relief is steeper (Bond, 2000).

ORGANIC DEPOSITS

Organic deposits occur as a post-glacial accumulation of peat and decomposed woody debris. The spatial distribution of these deposits is wide ranging and varies according to topography. Widespread organic deposits are found near the base of the upland that borders the east side of the map area. Locally distributed organic deposits occur in the many small drainages that have limited catchments, marginal to lakes where drainage is poor, and on flat surfaces that have old growth black spruce forests. Permafrost is commonly within one metre of the surface and standing water may be present where surface permafrost has melted. Minor alluvium may be interbedded within the organic accumulation.

ALLUVIAL DEPOSITS

Alluvial deposits occur as post-glacial accumulations of fluvially deposited silt, sand and gravel. Two types of alluvial deposits have been classified and include: sand and gravel deposited along active stream beds, which may be subjected to seasonal flooding, and silt and sand deposited by low-volume streams that have poorly defined channels. The latter includes streams from small catchments or artisian sources that have limited energy for erosion and deposit fine-grained sediment. Landform associations include: alluvial fans, floodplains in small drainages, and low relief areas at the base of high relief north- or west-facing slopes.

Actively deposited coarse-grained alluvium is most common along the Pelly River and in one drainage located in the northeast part of the map area (Bond, 2000). Fine-grained alluvium is common in the east-central part of the map area.

COLLUVIAL DEPOSITS

Colluvium consists of any surficial deposit or bedrock that is remobilized by physical and chemical weathering and transported downslope under gravitational forces. Sediment that is commonly amassed in colluvial deposits includes: fractured bedrock, till and organics. The amount of each component depends on the topographic setting. Colluviation will be enhanced on north- and west-facing slopes where permafrost is commonly present.

Slopes that are prone to surface deposit colluviation are located intermittently along the eastern edge of the map area. Isolated colluvial deposits were also found on the flanks of small uplands elsewhere in the study area. These are commonly associated with resistant bedrock outcrops of basalt and greenstone, which create relatively steep slopes.

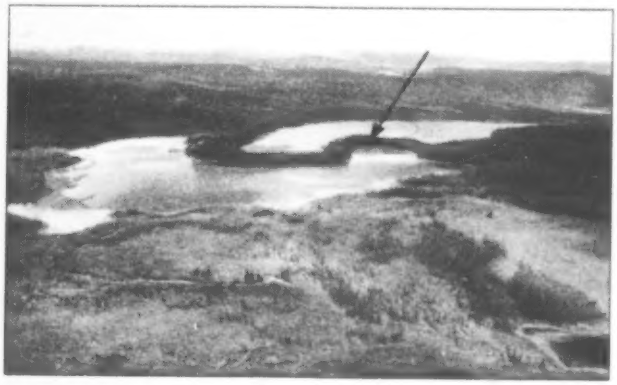


Figure 6. Aerial photo of an esker in central Weasel Lake map area.

GLACIOLACUSTRINE DEPOSITS

Glaciolacustrine deposits occur as deglacial accumulations of clay and silt that are deposited into lake basins by glacial meltwater. The deposits occur as laminated varves of clay, silt and minor sand. Sporadic drop-stones and coarse-grained mudflow deposits may be present if the lake was proximal to the ice sheet.

Glaciolacustrine deposits are found at depth in the Quaternary stratigraphy along the Pelly River (Jackson, 1994).

GLACIOFLUVIAL DEPOSITS

Glaciofluvial deposits are deposited by glacial meltwater and consist of regionally derived accumulations of sand and gravel. These types of deposits are found in two general sedimentary environments: proximal deposition in contact with the former glacier (glaciofluvial complexes) and distal deposition of outwash plains or channel deposits (glaciofluvial plains and terraces). Glaciofluvial complexes include landforms such as eskers, kames and kettled outwash surfaces (Fig. 6).

Glaciofluvial deposits are common along the Pelly River and in the northeastern part of the map area (Bond, 2000).

GLACIAL TILL

Glacial till consists of sediment that is deposited directly from the glacial ice. Deposition can occur at the base of the glacier in the form of basal till, or by a melting glacier as an ablation till. A till is loosely defined as a poorly sorted mixture of gravel, sand and mud deposited by a glacier (Eyles, 1983). There are, however, a wide range of depositional environments in which poorly sorted sediments are produced. These are especially important to be aware of since different tills will have different transport distances associated with them. The three most common types of till observed in the study area were basal lodgement, basal meltout and ablation tills. Basal lodgement and basal meltout tills are deposited directly from the base of the ice sheet and consist of sediment that has relatively short transport distances ranging from 1-8 km. This is the primary medium sampled for till geochemistry studies. In contrast, ablation tills are deposited where a melting ice sheet remained stagnant

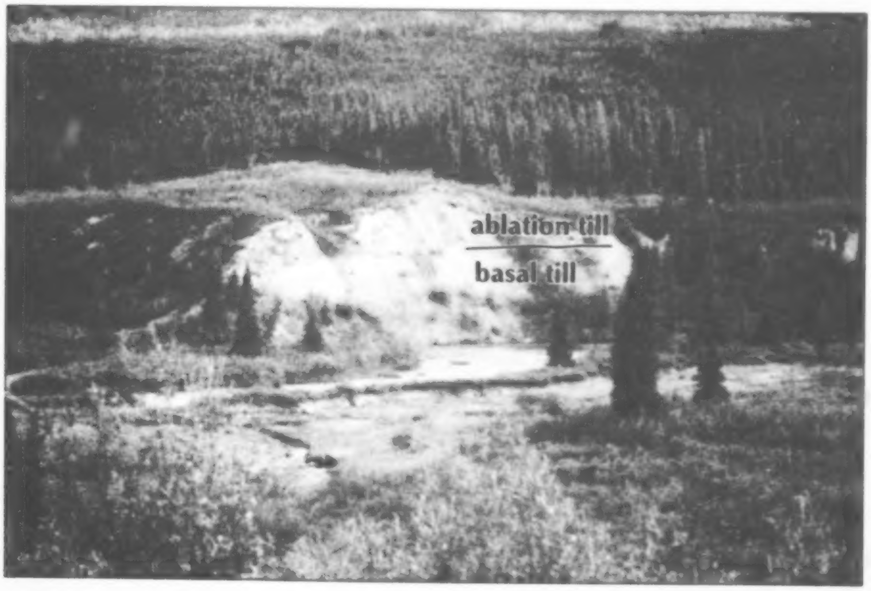


Figure 7. Stream-cut exposure showing ablation till (deglacial sediment) overlying basal till (glacial maximum sediment) in the upper McMillan River valley, northeast of Weasel Lake map area.

for an extended period of time. This allows for extensive thicknesses of meltout debris to be deposited. Ablation till is a collection of sediment that is composed of material carried within different levels of the former ice sheet. Initially, when the ice begins to melt, a basal meltout till is deposited. As the ice continues to melt, sediment that is carried within the ice (englacial) and sediment carried on the surface of the ice sheet (supra-glacial) is deposited onto the basal strata (Fig. 7). Blocks of glacial ice are also incorporated into the sediment package and create a hummocky topography after melting. Sediment derived from the englacial and supraglacial strata of the former ice sheet is typically far travelled and not representative of underlying bedrock.

In Weasel Lake map area, basal tills have been categorized into two divisions based on presumed thickness. Basal till veneers are less than one metre in thickness and are commonly found on plateau summits and on slopes that faced into the direction of glacial flow. Basal till blankets are greater than one metre in thickness and are often mapped in local depressions and on slopes that are in the lee direction to the advancing ice sheet. Basal till blankets are widespread across the map area (Bond, 2000).

Ablation tills are mapped as till complexes and also include minor deposition by glaciofluvial processes. Till complexes are common in the northeast part of the map area and are often located near glaciofluvial complexes.

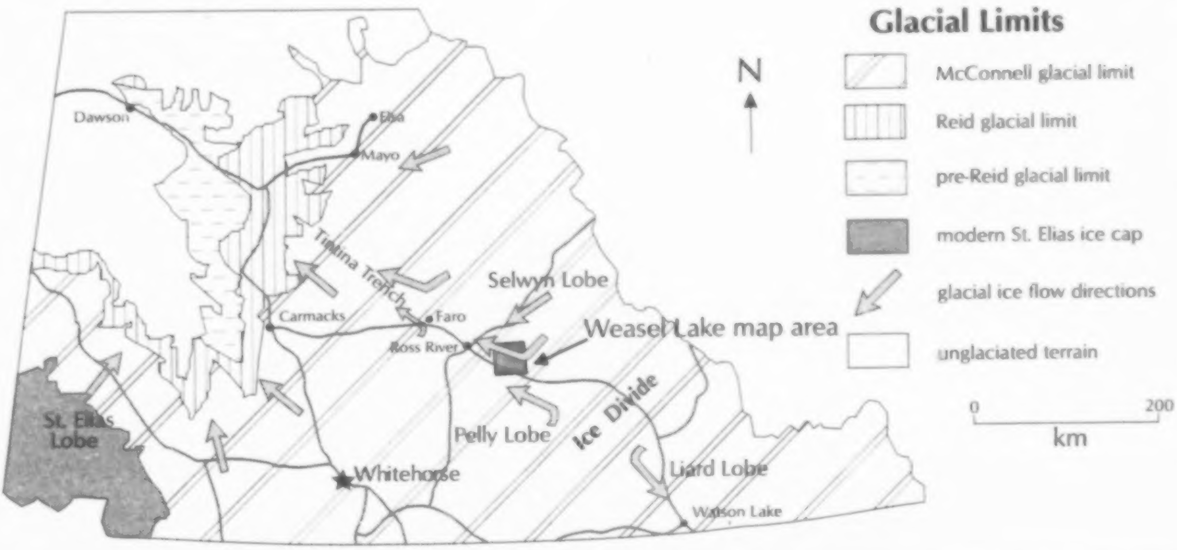
QUATERNARY GEOLOGIC HISTORY

The late Wisconsinan McConnell glaciation and the current Holocene interglacial period are the most recent Quaternary events to impact the Weasel Lake area. These two periods can account for the current surficial geological setting.

McCONNELL GLACIATION

Ice accumulation in east-central Yukon occurred in the Selwyn mountains at the divide with the Northwest Territories, and in the Pelly Mountains to the south (Fig. 8). Weasel Lake map area is located approximately 75 km northwest of a regional ice divide that developed during the last glaciation (Jackson, 1994). The ice divide (Fig. 8) corresponds roughly with the current hydrologic divide between Yukon River and Liard River drainages.

Ice flow through the Weasel Lake area at glacial maximum was between 300° and 310°. Streamlined landforms such as crag and tails, and glacial grooves in bedrock, provide the evidence for the ice flow history. No variations in ice flow due to topographic control were noted. It is presumed that during glacial maximum, ice


Glacial Limits
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modern St. Elias ice cap
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Elsa
Mayo
Tintina Trench
Selwyn Lobe
Carmacks
Faro
Ross River
Weasel Lake map area
St. Elias Lobe
Pelly Lobe
Ice Divide
Whitehorse
Liard Lobe
Watson Lake

Figure 8. Glacial limits, ice centres and ice-flow patterns for southern Yukon.

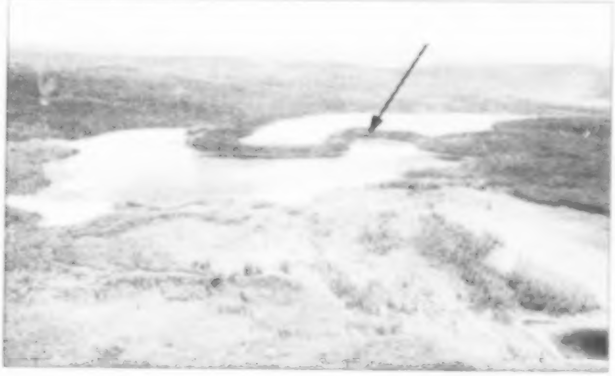

Figure 6. *Aerial photo of an esker in central Weasel Lake map area.*

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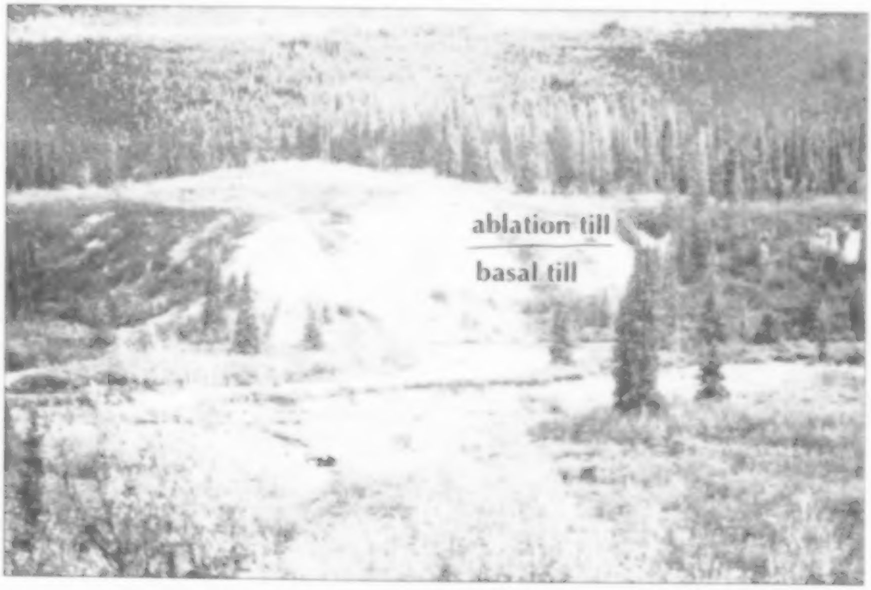

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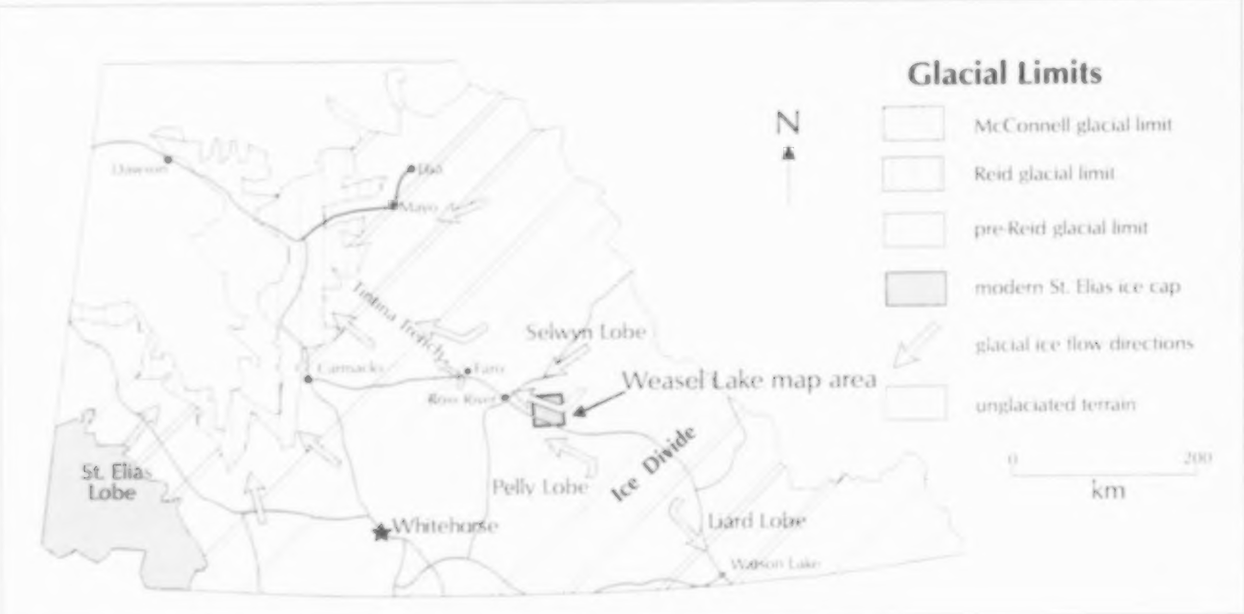
Glacial Limits
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Watson Lake

Figure 8. *Glacial limits, ice centres and ice-flow patterns for southern Yukon.*

flow was relatively rapid because of the low topographic relief. The abundance of streamlined landforms also supports this conclusion.

During the waning stages of the glaciation, the ice sheet thinned and became topographically controlled. Evidence of valley-confined ice-flow is present only in the southeast corner of the map area where the topography is higher. Some late stage fluctuations in ice flow occurred in the northeast corner of the map area where stagnating ice persisted.

The Pelly River valley was a focus for glacial deposition at the end of the McConnell glaciation. Stagnating ice persisted in the valley, and as a result, deposited thick packages of meltout debris. As a regional topographic low, the valley also acted as a major conduit for meltwater drainage. The combination of deposition and drainage resulted in a damming of meltwater and the creation of pro-glacial lakes. A succession of lakes, in contact with the ice, formed as the ice retreated east towards Finlayson Lake. Finlayson Lake is dammed behind one of these sediment accumulations and is a remnant of the post-glacial environment.

HOLOCENE

Holocene erosion has been most significant in the Pelly River valley. Incision into the deglacial sediment package has created a series of terraces bordering the modern floodplain. Drainages emanating from the eastern highlands have also incised into glacial deposits. Elsewhere in the map area, erosion has been minimal due to the overall low hydrologic flow.

SURVEY METHODOLOGY

SAMPLE COLLECTION

Initial work consisted of compiling and evaluating existing surficial geology maps, bedrock geology maps, geophysical maps and MINFILE occurrences. Air photographic interpretation also preceded fieldwork and provided a guide to the distribution of surficial deposits.

Fieldwork was based from camps established on ten different lakes in the map area (Fig. 9). Access to the area and between camps was provided by a Beaver floatplane. A Zodiac was used to access traverse starting points. No roads, other than the Robert Campbell highway in the southwest corner of the map area, are present within the study area. All samples were collected during daily foot traverses from the lakeshore. Till samples were collected along crude traverse lines oriented perpendicular to sub-perpendicular to the former ice-flow direction. This enabled maximum geochemical coverage of the underlying geology.

At each sample station, a 2-kg bulk sediment sample was collected for geochemical analysis. Emphasis was placed on sampling basal lodgement till, although colluviated basal till and basal meltout till were also collected. Hand excavation was used to expose the C-horizon sediment or unweathered parent material (Fig. 10). On average, the pit depth was 55 cm. Natural exposures were uncommon in the map area. In addition to the 2-kg bulk sample, fifty pebbles were collected in a separate bag to be used for a lithological record.

Figure 9. *Typical base-camp in the northern part of Weasel Lake map area.*

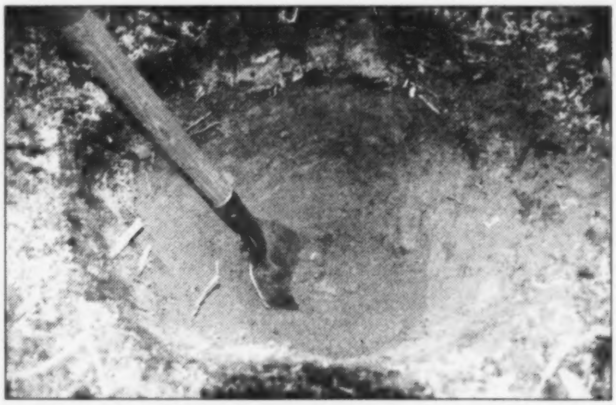

Figure 10. *Hand pit exposing a basal lodgement till in the study area. This is ideal surficial sediment for till geochemistry studies. On well drained sites such as this, the organic horizon is thin and permafrost is usually absent near the surface.*

The following information was recorded onto data sheets at each sample site: UTM coordinates, elevation, slope, aspect, surficial map unit, topographic position, bedrock, drainage, vegetation, soil properties (i.e., density, oxidation, depth and presence of permafrost), matrix properties (i.e., percent matrix, colour and texture), and a basic clast shape description (Fig. 11).

Additional information that was recorded in the field included the location of outcrops (some samples were taken), general bedrock descriptions, and presence and orientation of glacial ice-flow features.

SAMPLE PREPARATION AND ANALYSIS

Till samples were dried, sieved and assayed by Acme Analytical Laboratories in Vancouver, British Columbia. Sample preparation included drying 1 kg of sample at 60 °C, followed by splitting and sieving to produce a -63 micron or -230 mesh fraction. A 30 g sample of the -63 micron fraction was subsequently analysed for 37 elements by aqua regia digestion – Ultratrace-ICP mass spectrometer. This method offers near total precious and base metal data, but acts as a partial leach for rock-forming elements. As a result, the measured element concentrations for Cr, Fe, Mg, S, Sr and Ti are lower than the actual concentrations in the till. Detection limits for the elements are shown in Table 1.

Figure 11. *Site data was recorded on field forms that were later entered into an Access database. This type of information will be integrated into the digital surficial geology map for release in 2001.*

QUALITY CONTROL

METHODOLOGY

Distinguishing geochemical trends caused by geological changes from those variations due to sampling or analytical errors is important for reliably interpreting regional till geochemical data (Bobrowsky et al., 1998). The quality control methodology for this project was adapted from the British Columbia Geological Survey. In every block of 20 samples, two field duplicates and one control standard were inserted. The control standards are CANMET reference standards collected and prepared at the Mineral Resources Division of the Geological Survey of Canada. They are inserted into the data set for use as 'known' samples to test the precision of the analytical lab. The field duplicates consist of an additional sample collected at random from one in every ten till sampling stations. These duplicates are used to test geochemical variation within the till. No analytical duplicates (sieved splits) were included because Acme Analytical conducted both the processing and the assaying. In total, the quality control consisted of 16 pairs of field duplicates and 9 control standards in the 175 samples collected.

Table 1. *Detection limits for the elements analysed by ICP-MS in this study.*

Element	Detection limit		Element	Detection limit	
Au	0.2	ppb	**Mo**	0.01	ppm
Ag	2	ppb	**Na**	0.001	%
Al	0.01	%	**Ni**	0.1	ppm
As	0.1	ppm	**P**	0.001	%
B	1	ppm	**Pb**	0.01	ppm
Ba	0.5	ppm	**S**	0.02	%
Bi	0.02	ppm	**Sb**	0.02	ppm
Ca	0.01	%	**Sc**	0.1	ppm
Cd	0.01	ppm	**Se**	0.1	ppm
Co	0.1	ppm	**Sr**	0.5	ppm
Cr	0.5	ppm	**Te**	0.02	ppm
Cu	0.01	ppm	**Th**	0.1	ppm
Fe	0.01	%	**Ti**	0.001	%
Hg	5	ppb	**Tl**	0.02	ppm
Ga	0.02	ppm	**U**	0.1	ppm
K	0.01	%	**V**	2	ppm
La	0.5	ppm	**W**	0.2	ppm
Mg	0.01	%	**Zn**	0.1	ppm
Mn	1	ppm			

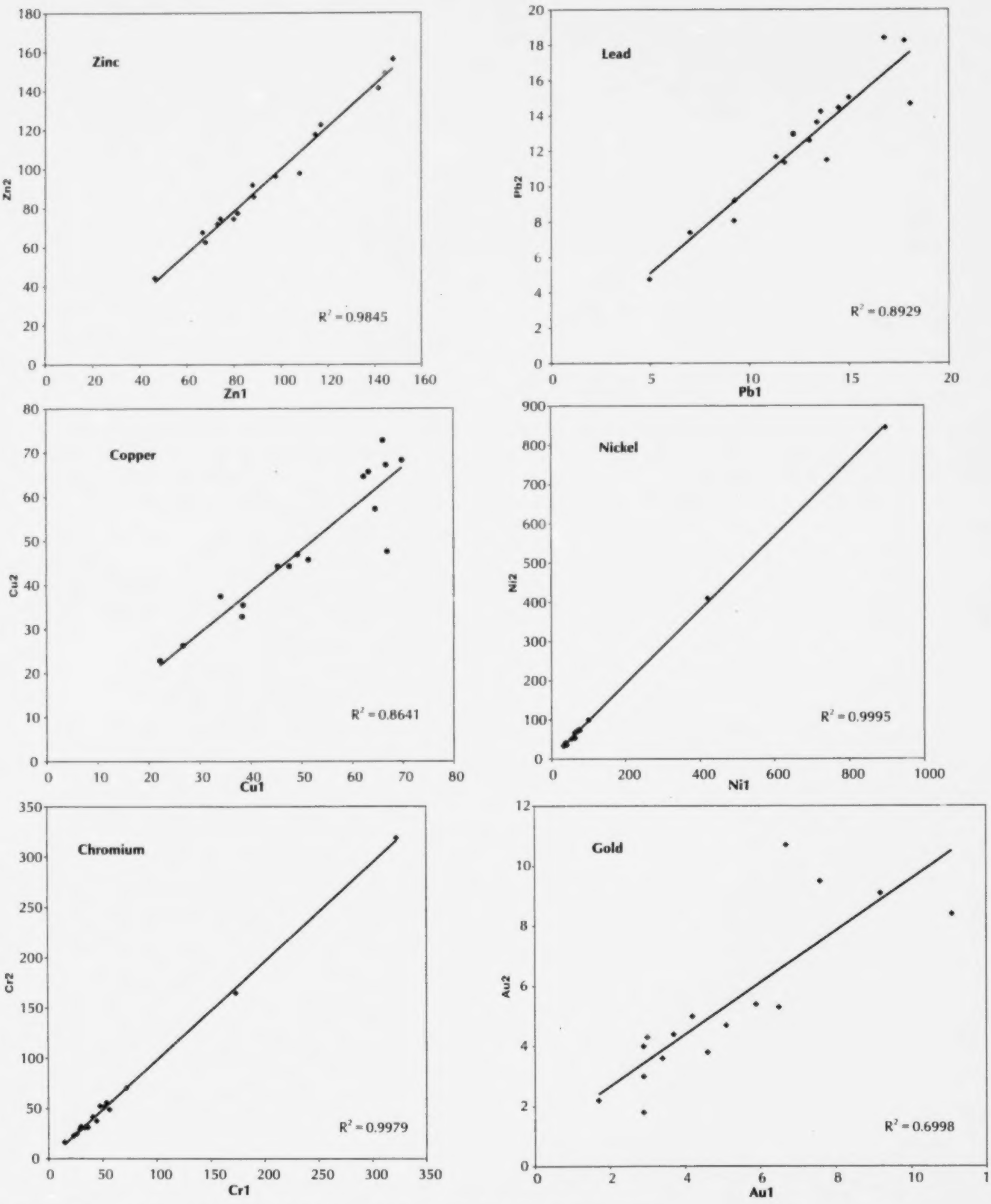

Figure 12. Bivariate scatter plots of the field duplicate data for selected elements.

Scattered plots of the field duplicate pairs were generated to facilitate quality control evaluation (Fig. 12). The results show good correlation between the field duplicate pairs, with the correlation coefficients ranging from 0.6998 to 0.9995. The degree of correlation depends somewhat on the presence of anomalous outliers in the data set. For nickel and chromium, the correlation coefficients are higher for this reason. Gold shows the least amount of correlation within the field duplicates. This is expected because of the nugget effect.

TILL GEOCHEMISTRY – DATA INTERPRETATION

The elements presented here are considered to be significant for exploration purposes in the Weasel Lake area. The results, with the exception of one sample site (JB00-155), are media specific and compare only basal till or colluviated basal till. This ensures that the parent materials sampled are local in origin. Transport distances are on the order of tens of metres to a few kilometres depending on the sample setting. See Appendix I for a sample location map and the related element concentration maps.

COPPER

The 175 samples collected and analysed by ICP-MS provided copper concentrations ranging from 11.72 ppm to 128.73 ppm. The samples generated a mean of 47.47 ppm; the median value is 44.29 ppm. The four highest values, corresponding to values above the 97th percentile, are discussed below.

The highest concentration of copper, 128 ppm, is recorded from a basal till sample collected in the northwest corner of the map area from station JB00-156. The sample was collected from a till veneer (48 cm thick) that overlies graphitic schist bedrock. The colour of the till strongly reflected its dark bedrock source. The source area for the elevated copper is most likely within a hundred metres 'up ice-flow' of the sample station. The significance of this value may be rated somewhat lower than lesser values that occur in thick till because of the proximity of bedrock to the surface. In other words, the geochemistry of the till and the bedrock may not vary significantly and this is not an especially high value for a bedrock assay. Further sampling of bedrock and till in this area is warranted to verify this assumption.

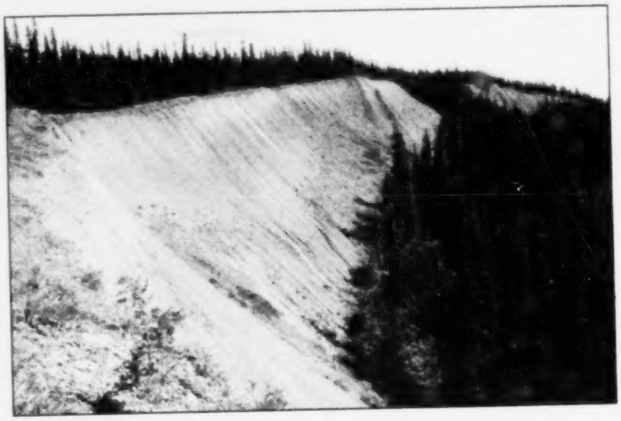

Figure 13. *Exposure of basal till in the western part of Weasel Lake map area. The section thickness is approximately 40 m.*

The second highest copper value, 110 ppm, is obtained from station JB00-046. This sample was collected from an area with a high permafrost table. A frost boil was sampled that had the texture of a basal till. The matrix, however, had a micaceous feel, and numerous angular clasts were found. It is believed that this sample may be derived from fault gouge and as a result, is composed of local bedrock. Similar to JB00-156, the significance of this sample may be rated lower than a sample derived from thicker till cover.

The third highest copper value, 96 ppm, was obtained from a basal till sample collected from station JB00-064. This station is located on the former Neck claims. A source for this anomaly is likely located within two kilometres in the up-ice flow direction of the sample station. This station also boasts appreciably high mercury, zinc and silver values.

The fourth highest concentration of copper, 94 ppm, was recorded from a basal till sample collected at station JB00-050. The station is located down-ice flow from the ASSIST claims, which is a likely source area for the anomaly. This station also has a relatively high silver concentration.

ZINC

Zinc concentrations ranged from 43.8 ppm to 348.6 ppm. A mean value of 103.57 ppm and a median value of 97.05 ppm result from this distribution. The five highest values (>97th percentile) are discussed below.

The highest concentration of zinc, 348 ppm, was collected from a basal till sample in the central part of the map area at station JB00-047. A potential source for the anomaly may be derived from the ASSIST claims that are located in the up-ice flow direction. The source may also be located closer to the sample station. Zinc values from JB00-050 and 051, immediately down-ice flow of the ASSIST claims, are not elevated in zinc, which suggests the potential source for JB00-047 is nearby. Follow-up sampling should be completed to confirm this.

The second highest concentration of zinc, 337 ppm, was recorded from a colluviated basal till veneer collected from station JB00-006. The source for the till sampled at this station is most likely to have a local origin. A potential source probably lies within one kilometre up-ice flow. Outcrop in the vicinity also suggests a thin surficial cover and a local origin for the anomaly.

The third highest zinc anomaly, 210 ppm, was recorded from station JB00-156, which also had the highest copper value. As mentioned previously, this sample was derived from a thin till cover and therefore the geochemistry is a direct indication of local bedrock geochemistry. This station is located in ancient North American rocks of the Cassiar Platform and therefore SEDEX-style mineralization may be the target for this anomaly.

The fourth highest zinc anomaly, 187 ppm, is recorded from station JB00-127. This anomaly is located proximal to an extensive Tertiary basalt outcrop at the north end of Weasel Lake. No other elements are anomalous with this sample. An origin for the anomaly is likely north of the Pin claims.

The fifth highest concentration of zinc, 171 ppm, was recorded from a 40-m exposure of basal till at station JB00-076 (Fig. 13). A high percentage of graphitic or black shale clasts occur within the till and some oxidized clasts were also present. A source for the anomaly is most likely to be between JB00-076 and JB00-084. JB00-084 is 2.5 km up-ice flow from the sample station and only weakly anomalous in zinc. Similar clasts in till were also found less than 1 km away at JB00-077. The geochemistry at this sample station is weakly anomalous in zinc (134 ppm). Relatively high lead and silver were also associated with JB00-076.

LEAD

The mean concentration of lead in the 175 samples was 13.34 ppm. The median value was 12.93 ppm. The four highest lead values, corresponding to values above the 97th percentile, are discussed below.

The highest concentration of lead, 36 ppm, is recorded from a basal till sample collected in the northwest corner of the map from station JB00-159. The source area for the elevated lead is most likely within 2 km in the up-ice flow direction. Numerous angular and subangular clasts were noted within the till, which suggests a relatively proximal source. Two additional anomalous lead values (22 ppm) were encountered nearby at stations JB00-155 and JB00-157.

The second highest concentration of lead, 30 ppm, was collected from station JB00-054 in the central part of the map area. The sample was taken from a veneer of basal till, which suggests a proximal source for the anomaly, probably within 1 km.

The third highest lead value, 24 ppm, was collected from station JB00-076. This site was discussed previously and has an anomalous zinc concentration (171 ppm).

The fourth highest concentration of lead, 23 ppm, was collected from station JB00-048. The anomaly may be originating from the ASSIST claims, which are located 2 km from the station. Numerous strongly oxidized clasts were noted within the soil profile.

GOLD

Gold concentrations were calculated as part of the ICP-MS process and were not derived from fire assay. The mean and median concentrations of gold are 5.14 ppb and 4.7 ppb, respectively. Values ranged from 0.9 ppb to 28.9 ppb for the 175 samples analysed. The four highest gold values are discussed below.

The highest concentration of gold, 28.9 ppb, was recorded from a mudflow-like deposit in the northwest corner of the map area at station JB00-155. The sample was collected on a small peninsula in a lake that was noted to have a highly oxidized soil, visible from a distance. A source for the anomaly is either from a small valley that drains into the lake from the west, or possibly at depth beneath the peninsula. The highest values for each of As (484.5 ppm), Sb (151.37 ppm), Hg (21020 ppb), Tl (1 ppm) and Ag (1374 ppb) originate from this sample station.

These pathfinder elements support an epithermal gold deposit geochemical model. In this model As, Sb, Hg and Tl surround and overlie the Au ore-bearing zone (Hoffman, 1986). If this style of mineralization existed, then the strong presence of these indicator elements suggests that the potential Au ore-bearing zone may be intact at depth or immediately west of this pathfinder element anomaly. A knob of bedrock was noted immediately west of this sample site and consisted of what appeared to be a conglomerate. Similar fragments of a conglomerate were also noted in the soil sample taken at JB00-155. Re-examination of this outcrop and the pebbles within the sample material should be undertaken. The matrix within the conglomerate pebbles appears to have an angular texture and it is presently unclear whether it is of sedimentary origin or hydrothermal fluid origin. A possible source for the hydrothermal fluid may be related to the Tertiary extrusives in the area. Major faults in the area that would assist in the migration of fluids include the Finlayson Lake fault zone. See the section on mercury for more information about this station.

The second highest concentration of gold, 13.8 ppb, was collected from JB00-047. This sample site was mentioned earlier and has elevated Zn, Pb and Cd concentrations.

The third highest concentration of gold, 12.7 ppb, was collected from an area of elevated Cu, Ni and Cr. The sample was collected at station JB00-110 from the tail of a crag and tail landform; the crag consisted of an outcrop of quartzite. Numerous angular clasts were noted in the till which suggests a strong geochemical influence from local bedrock.

The fourth highest concentration of gold, 12.0 ppb, was recorded from station JB00-050. This sample site is located immediately down-ice flow of the ASSIST claims. This sample also has elevated Cu (94 ppm) and Ag (1006 ppb) values.

SILVER

Concentration of silver ranged from 35 ppb to 1374 ppb. Mean and median values of 283.14 ppb and 231 ppb, respectively, are present. The three highest values are discussed below.

The highest silver value, 1374 ppb, was recorded from station JB00-155 and was discussed earlier in the section on gold.

The second highest silver value, 1153 ppb, was obtained from station JB00-076. This station was also discussed earlier as it has relatively high zinc and lead concentrations.

The third highest silver value, 1023 ppb, was recorded from station JB00-106 in the south-central part of the map area. Numerous angular clasts were noted in the soil profile, which suggests a relatively proximal source for the anomaly.

MERCURY

The 175 samples collected provided mercury concentrations ranging from 5 ppb to 21020 ppb. The samples generated a mean of 326.68 ppb and a median of 152 ppb. The outlying value of 21020 ppb accounts for the large difference between the mean and median. The four highest mercury values are discussed below.

The highest concentration of mercury, 21,020 ppb, located at JB00-155, has been discussed under the gold section.

Presently, it is uncertain which state mercury occurs in in the surficial environment at station JB00-155. The state may provide some clues about a source for the anomaly. Mercury in the form of cinnabar would have the ability to be transported as a heavy mineral; cinnabar is the most stable state for mercury in a mudflow environment. Alternatively, mercury may be transported as a vapour along brecciated zones within faults. The sample was derived from a soil matrix of clayey sand, which may have acted as a trap for a secondary concentration of mercury vapour being dispersed from beneath the sample site. The third possibility is that mercury was transported in groundwater as a soluble form of mercury to form a hydromorphic anomaly. This may put the source area to the west of the station where there is a small drainage and some topographic relief. This would be a similar source area as the mudflow hypothesis.

The clayey texture of the matrix at this station has a waxy feeling that resembles the texture of fault gouge. If this material is fault gouge, then it is probable that its surface expression lies some distance from its original source area. Initial work should concentrate upslope from the anomalous station and in the small drainage to the west-northwest.

The next four highest mercury values, 1981 ppb, 1970 ppb, 1164 ppb and 1062 ppb are clustered 6 km southeast of JB00-155 at stations JB00-062, JB00-063, JB00-074, and JB00-064, respectively. These stations are located in the vicinity of the Finlayson Lake fault zone and are adjacent to the Tertiary mafic volcanics. Zinc values in the 90th percentile range are also associated with these high mercury anomalies. A source for these anomalies is uncertain and may be related to the Finlayson Lake fault zone. Additional epithermal gold prospects should be considered in the northwestern part of Weasel Lake map area.

CHROMIUM

Chromium concentrations ranged from a minimum of 11.7 ppm to a maximum of 367.9 ppm for the samples included in this report. A mean value of 52.96 ppm and a median value of 40.25 ppm result from this distribution. The highest four values are discussed below.

The highest concentration of chromium, 367 ppm, was recorded from station JB00-046. The sample was collected from a frost boil and may consist of fault gouge material that was brought to surface by cryoturbation. This station was discussed in the section on copper.

A cluster of high chromium values is recorded in the east-central part of the map area. Mafic basalts underlie the area and outcrop is relatively abundant. The highest values from this area were 328 ppm, 322 ppm, and 250 ppm, recorded from stations JB00-114, JB00-112 and JB00-111, respectively. All samples were collected down-ice flow from local outcrops and therefore are likely representative of local geology. Corresponding anomalous nickel values are also present at these stations. Assaying did not include platinum group elements.

NICKEL

Nickel concentrations range from 13 ppm to 897 ppm for the samples discussed in this report. The mean nickel concentration is 81.36 ppm and the median value is 58.25 ppm. The four highest nickel values, corresponding to the 97th percentile of the data set, are discussed below. A reminder that for rock forming elements such as nickel, chromium, iron and magnesium, this method acts as a partial digestion. Therefore actual nickel values measured in the till and presented below are lower than true concentrations.

The highest concentrations of nickel are clustered in an area of outcropping mafic basalt in the east-central part of the map area at station JB00-112. Anomalous chromium values are also present at these sites. The highest nickel value, 897 ppm, is derived from basal till located on a till ridge down-ice flow from a basalt crag. A source for the anomaly is likely located within 1.5 km of the sample station, towards the bedrock crag.

The next three highest nickel concentrations, 433 ppm, 411 ppm and 338 ppm, are located within 2 km of JB00-112. These sample stations are JB00-114, JB00-110 and JB00116 respectively. The source for these anomalies is derived locally from the outcropping mafic basalts.

An oxidized basalt erratic was sampled between stations JB00-013 and JB00-014 in the south-central part of the map area. Assay results from a standard rock assay using ICP-ES returned values of 1478 ppm nickel, 871 ppm chromium and 19.93% magnesium.

SUMMARY AND RECOMMENDATIONS

This study integrated surficial geology mapping with till geochemical sampling as a drift exploration program. The aim of this data is to provide a good regional-scale study of the mineral potential for this drift-covered region.

Much of the area is overlain by till, glaciofluvial deposits, alluvium, colluvium and deposits of organics. Sporadic outcrops are found throughout the map area and are more common in the highlands along the eastern boundary. Permafrost is localized to poorly drained areas and on north- and west-facing slopes. Much of the till coverage in the map area consists of basal lodgement or basal meltout till. These deposits are ideal for till geochemistry. Ablation till is more common in the northeast part of the map area and is unsuitable for till geochemistry.

During the McConnell glaciation, ice flowed northwest between 300° and 310° over the study area. The source for the ice was the northern part of the Cordilleran ice sheet, and an ice divide located east of Finlayson Lake. The ice-flow direction varied little during the glaciation. Some deviations occurred during deglaciation when the ice became valley-confined in the highlands along the eastern boundary of the map area. Post-glacial erosion has been mostly restricted to the Pelly River and to local drainages emanating from the highlands. Overall, little displacement or erosion of the glacial sediment has occurred within the map area.

A total of 175 bulk basal till samples were collected from Weasel Lake map area for the till geochemistry study. The till sample density averaged one per 4 km^2 for the total survey area. This level of sample density provides a high level of regional information for future exploration.

The samples taken for geochemical analysis were representative of either basal till or colluviated basal till. ICP-MS instrumentation combined with an aqua-regia digestion were used to analyse the –230 mesh fraction of the till samples. The geochemical results indicated numerous anomalies in base metals, gold and platinum group pathfinders. They include:

- Potential epithermal gold mineralization in the northwest corner of the map area. This is supported by a multi-element anomaly in Hg, Sb, Ag, As, Au and Tl at station JB00-155. This may be related to the Finlayson Lake fault zone and Tertiary mafic volcanics in the area.
- Base metal anomalies in zinc and copper in the western part of the map area. Anomalies occur both within Yukon-Tanana Terrane and in ancient North American rocks of the Cassiar Platform. Most anomalies are not associated with current claim holdings in the area.
- Clusters of platinum group element pathfinders in the northeast part of the map area. These coincide with mafic basalts.

ACKNOWLEDGEMENTS

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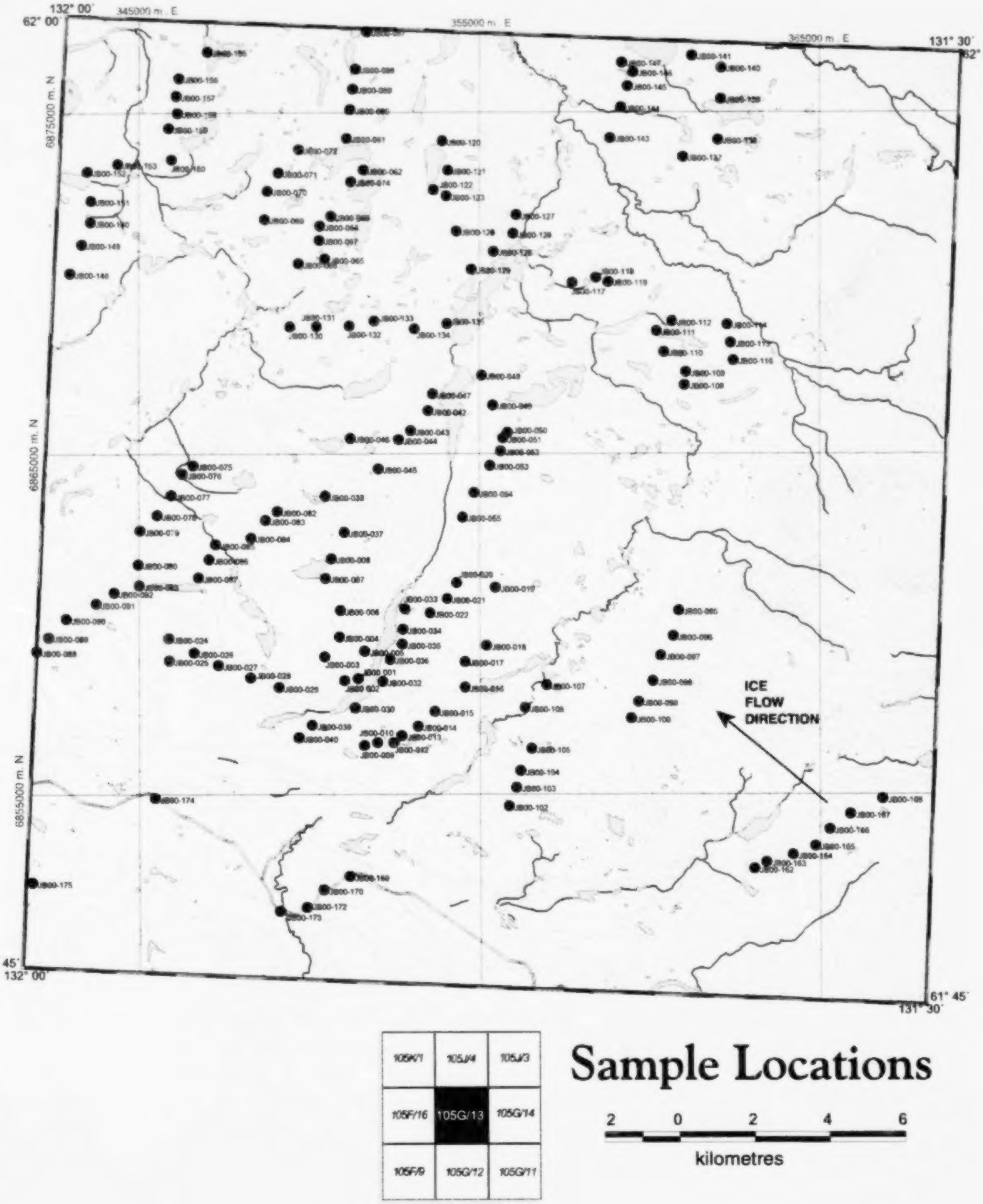
APPENDIX 1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Sample Locations

105G13

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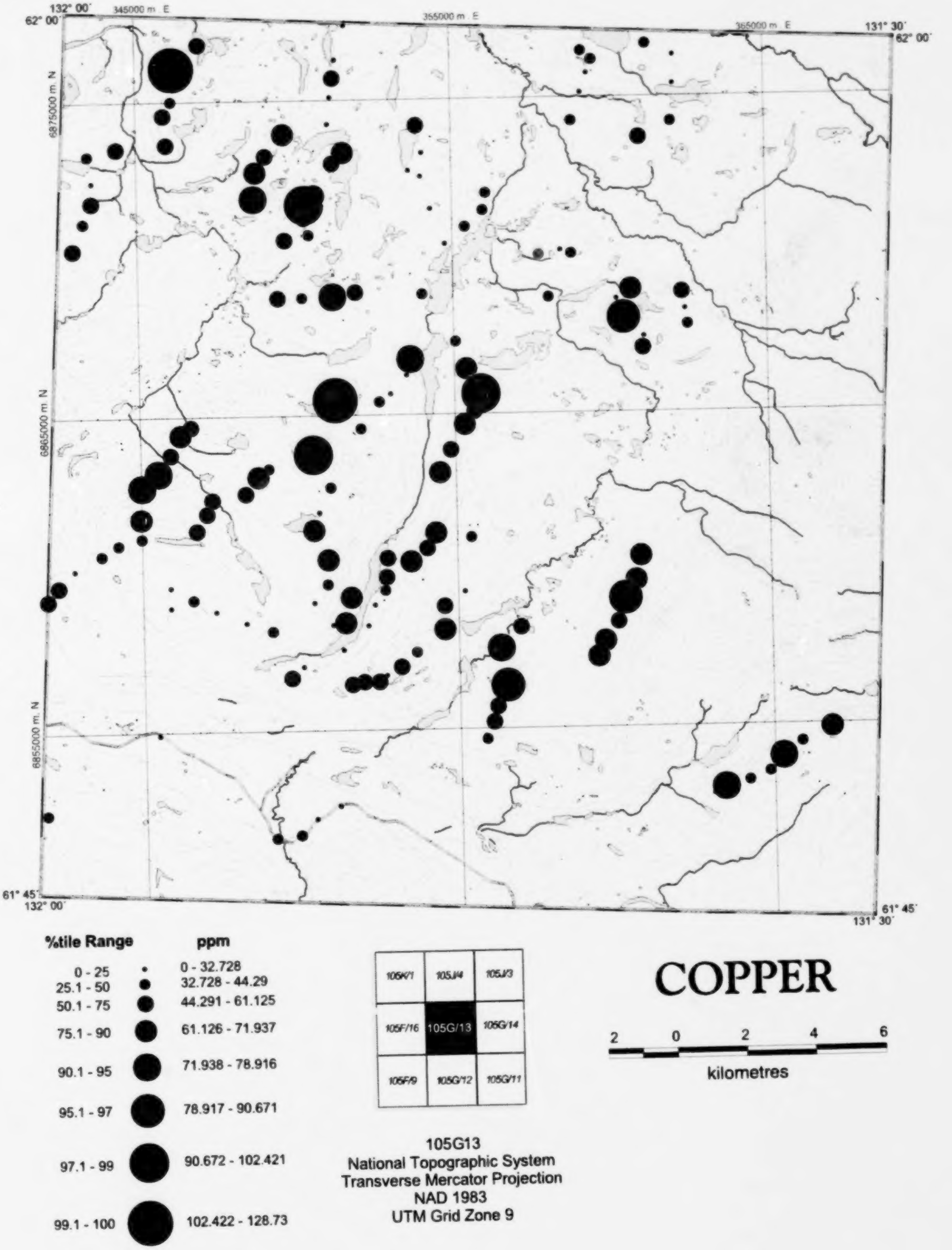
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%tile Range		ppm
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50.1 - 75	●	44.291 - 61.125
75.1 - 90	●	61.126 - 71.937
90.1 - 95	●	71.938 - 78.916
95.1 - 97	●	78.917 - 90.671
97.1 - 99	●	90.672 - 102.421
99.1 - 100	●	102.422 - 128.73

COPPER

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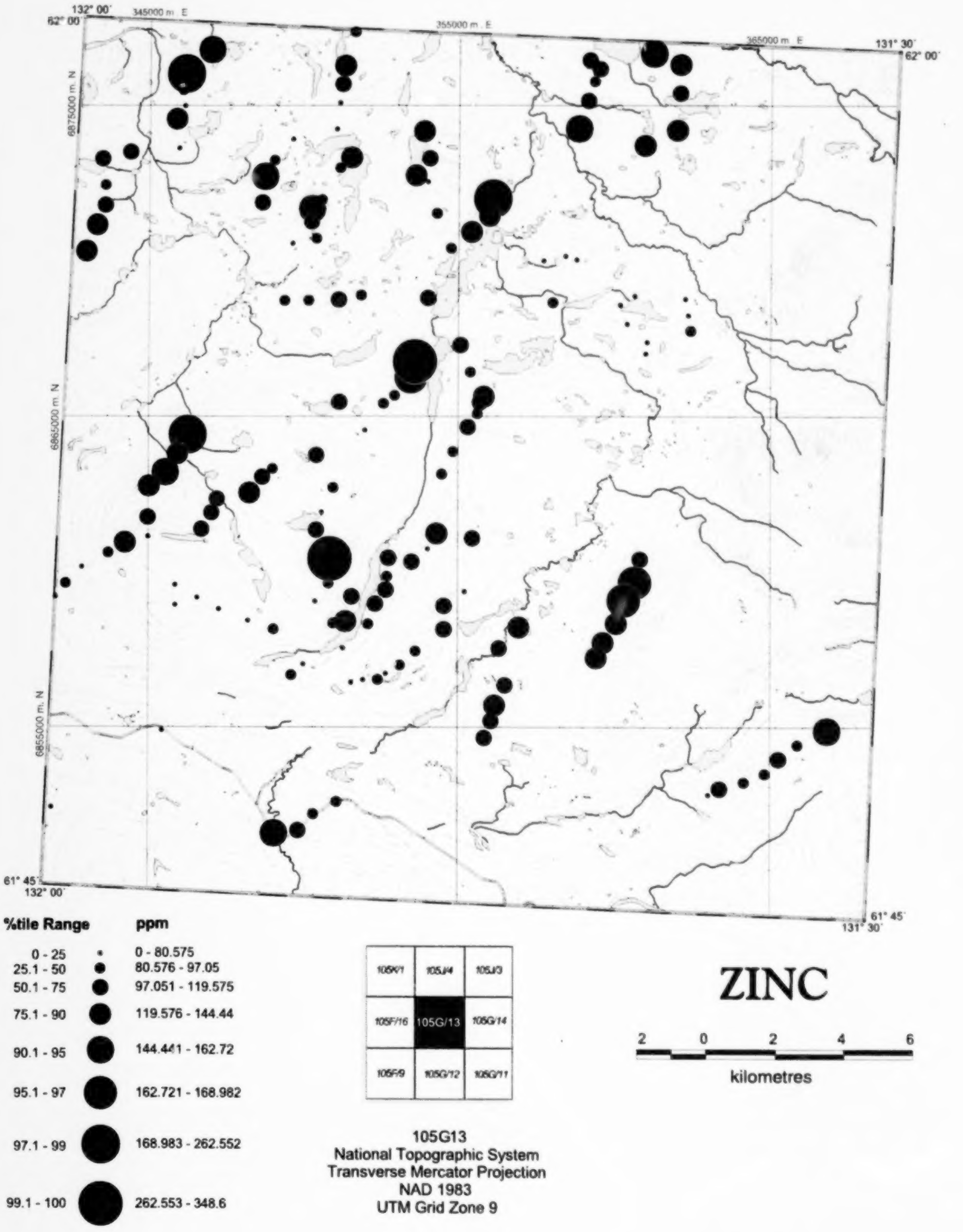
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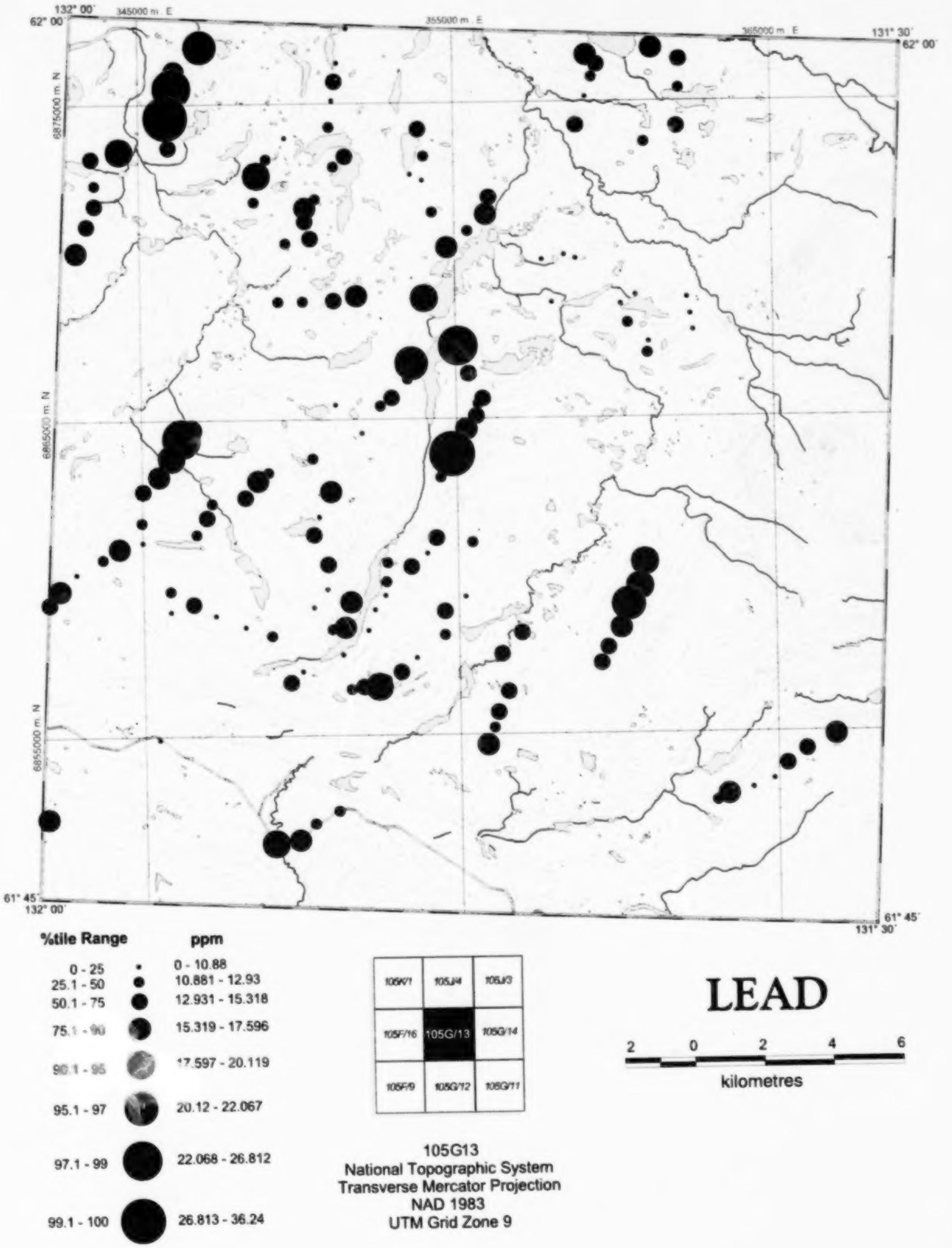
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95.1 - 97
20.12 - 22.067
97.1 - 99
22.068 - 26.812
99.1 - 100
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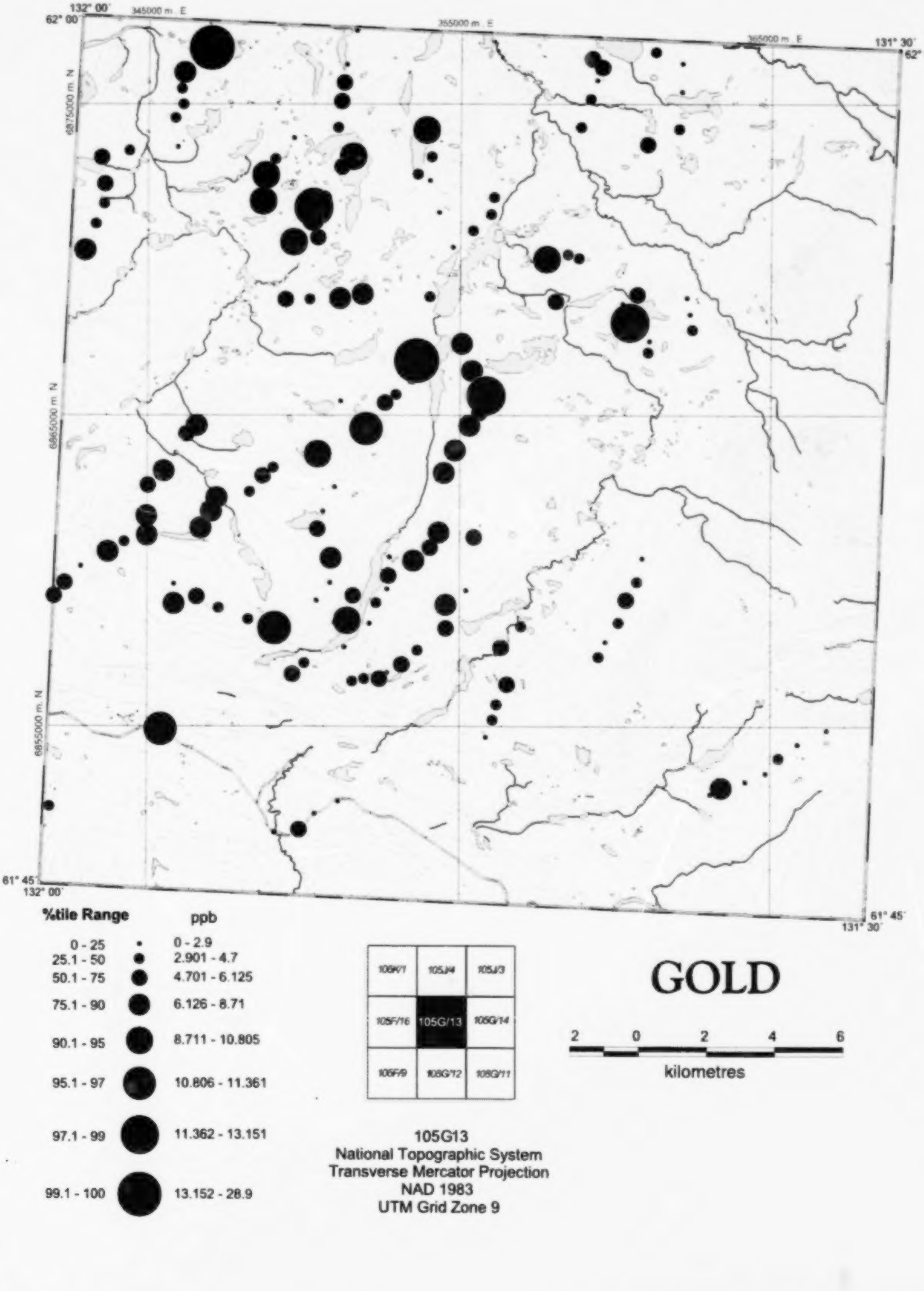
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75.1 - 90
6.126 - 8.71
90.1 - 95
8.711 - 10.805
95.1 - 97
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97.1 - 99
11.362 - 13.151
99.1 - 100
13.152 - 28.9
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105J/4
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105G/12
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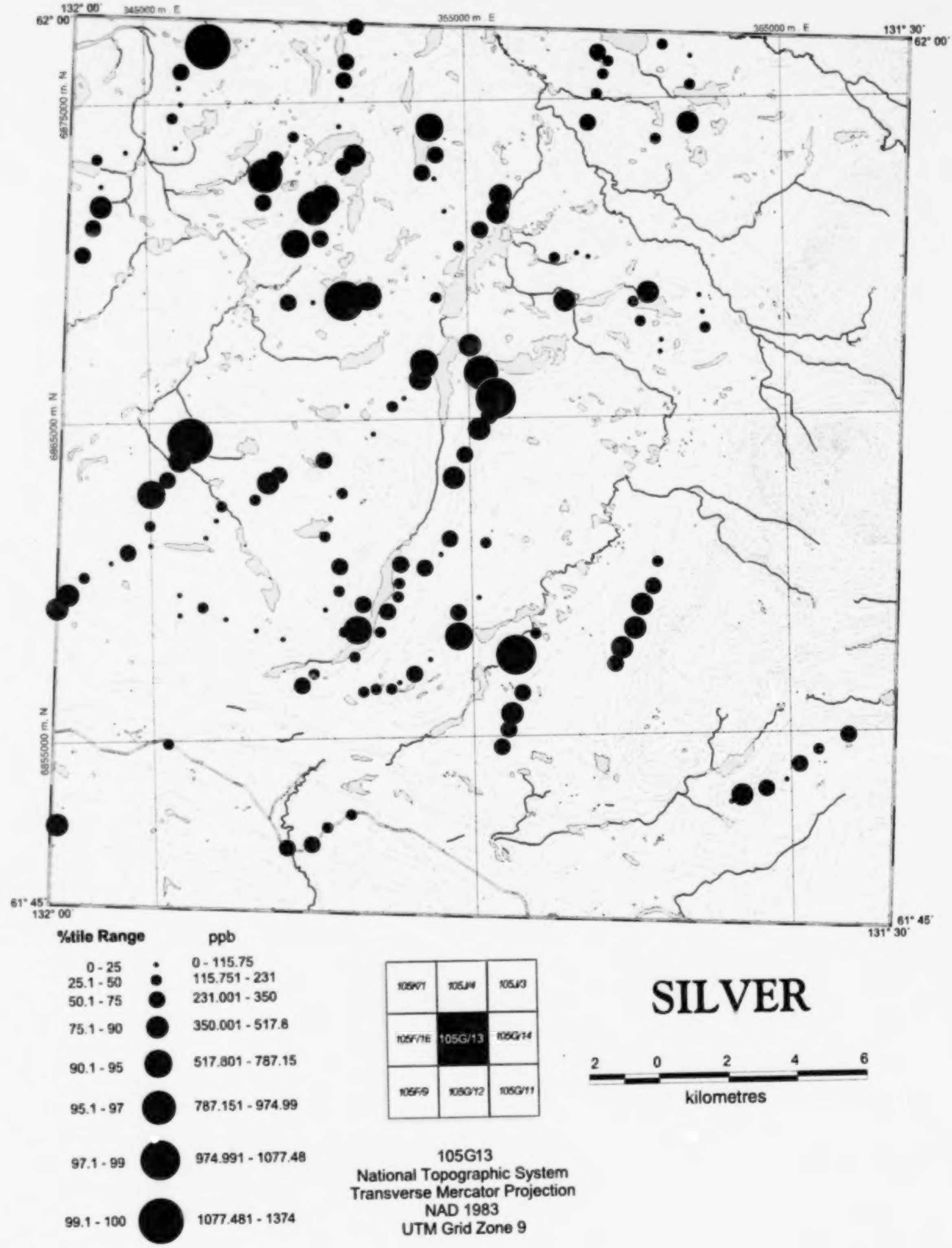
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61° 45'
132° 00'
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%tile Range
ppb
0 - 25
0 - 115.75
25.1 - 50
115.751 - 231
50.1 - 75
231.001 - 350
75.1 - 90
350.001 - 517.8
90.1 - 95
517.801 - 787.15
95.1 - 97
787.151 - 974.99
97.1 - 99
974.991 - 1077.48
99.1 - 100
1077.481 - 1374
105K/1
105J/4
105J/3
105F/16
105G/13
105G/14
105F/9
105G/12
105G/11
105G13
National Topographic System
Transverse Mercator Projection
NAD 1983
UTM Grid Zone 9
SILVER
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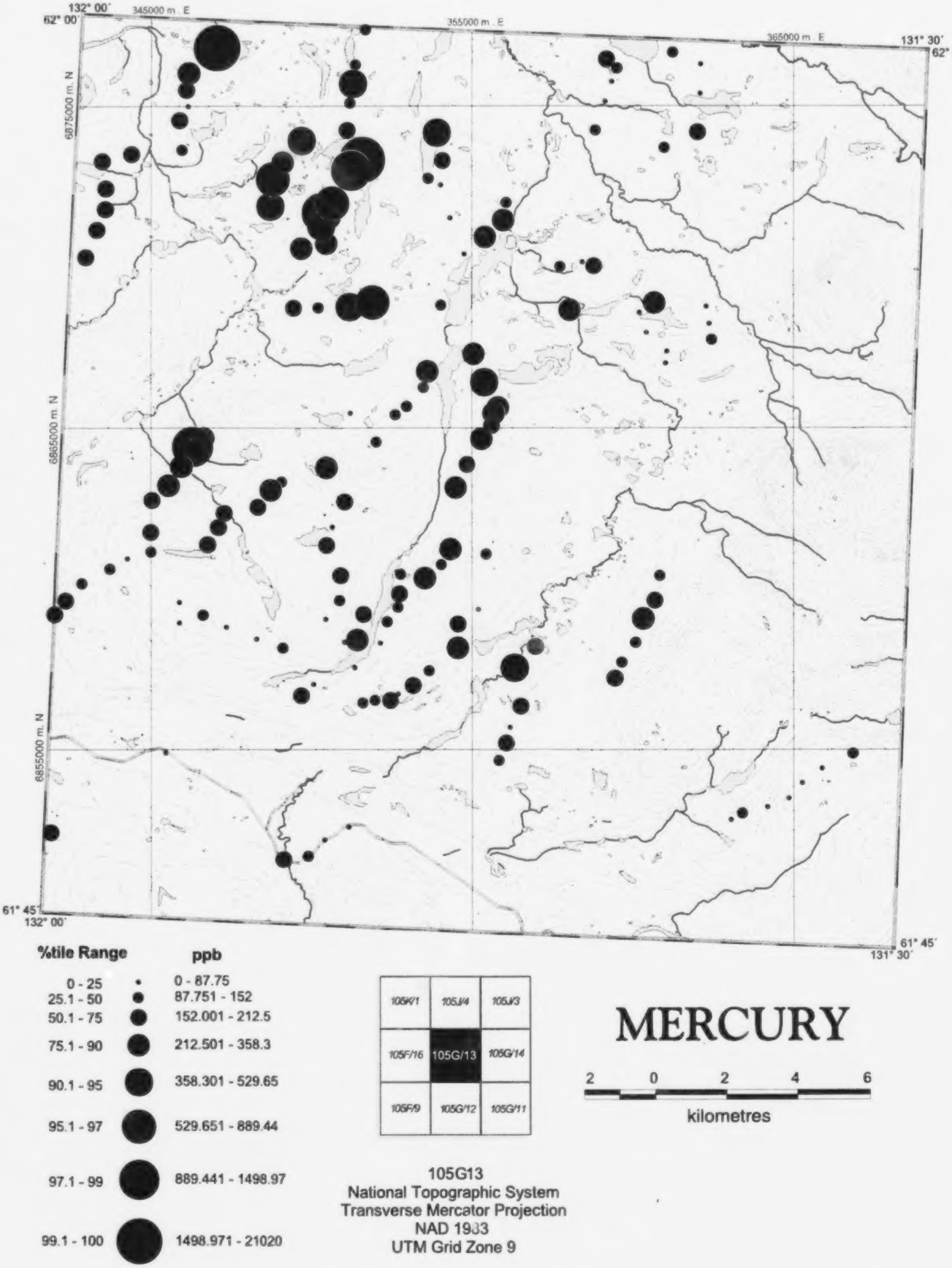
kilometres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%tile Range
ppb
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0 - 87.75
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87.751 - 152
50.1 - 75
152.001 - 212.5
75.1 - 90
212.501 - 358.3
90.1 - 95
358.301 - 529.65
95.1 - 97
529.651 - 889.44
97.1 - 99
889.441 - 1498.97
99.1 - 100
1498.971 - 21020
105K/1
105J/4
105J/3
105F/16
105G/13
105G/14
105F/9
105G/12
105G/11
MERCURY
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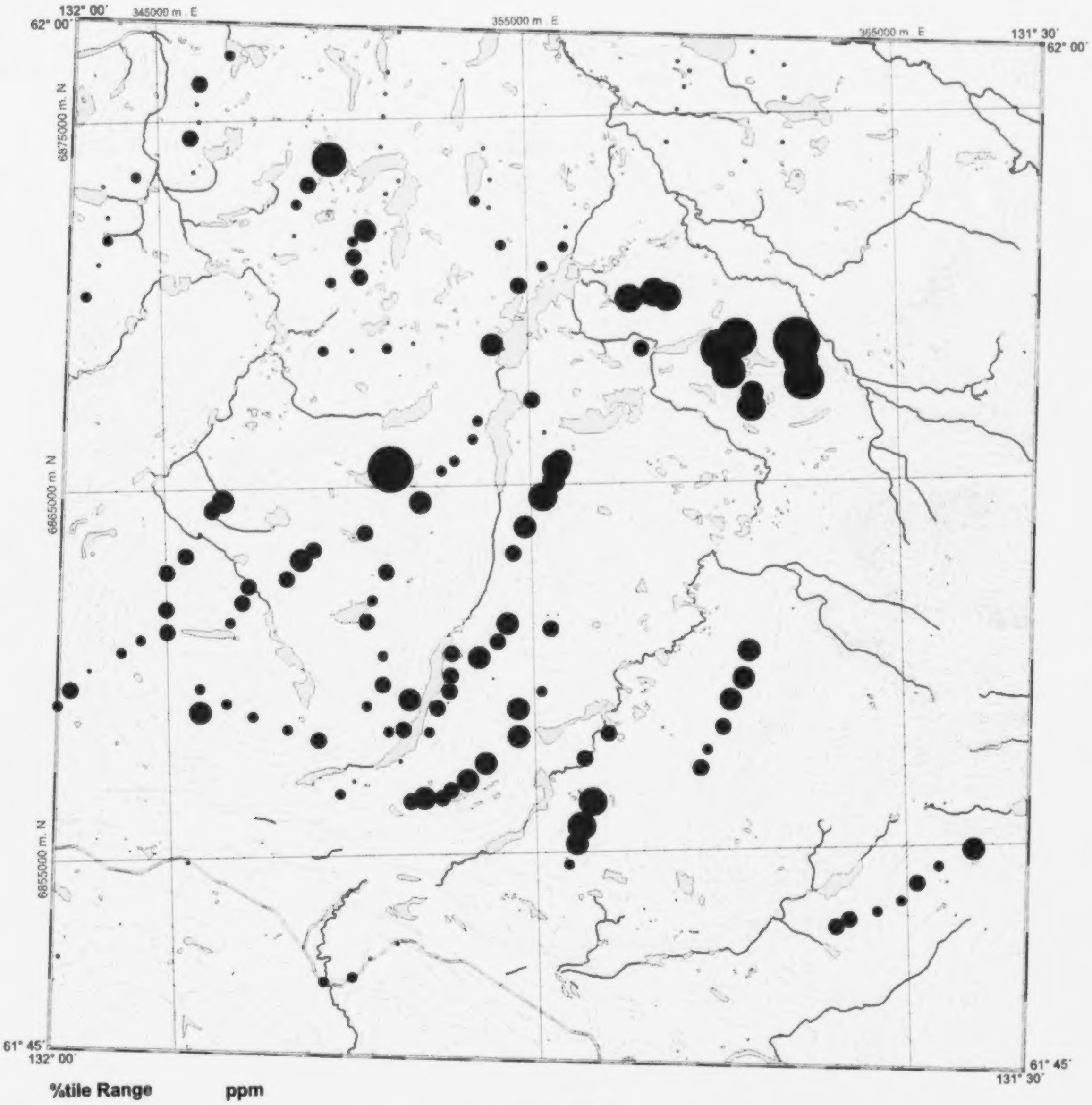
105G13
National Topographic System
Transverse Mercator Projection
NAD 1983
UTM Grid Zone 9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131° 30'

%tile Range		ppm
0 - 25	•	0 - 30.65
25.1 - 50	●	30.651 - 40.25
50.1 - 75	●	40.251 - 53
75.1 - 90	●	53.001 - 75.42
90.1 - 95	●	75.421 - 136.335
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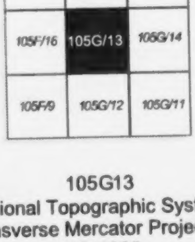
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105F/16
105G/13
105G/14
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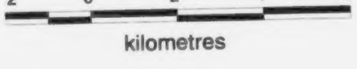
105G13
National Topographic System
Transverse Mercator Projection
NAD 1983
UTM Grid Zone 9

CHROMIUM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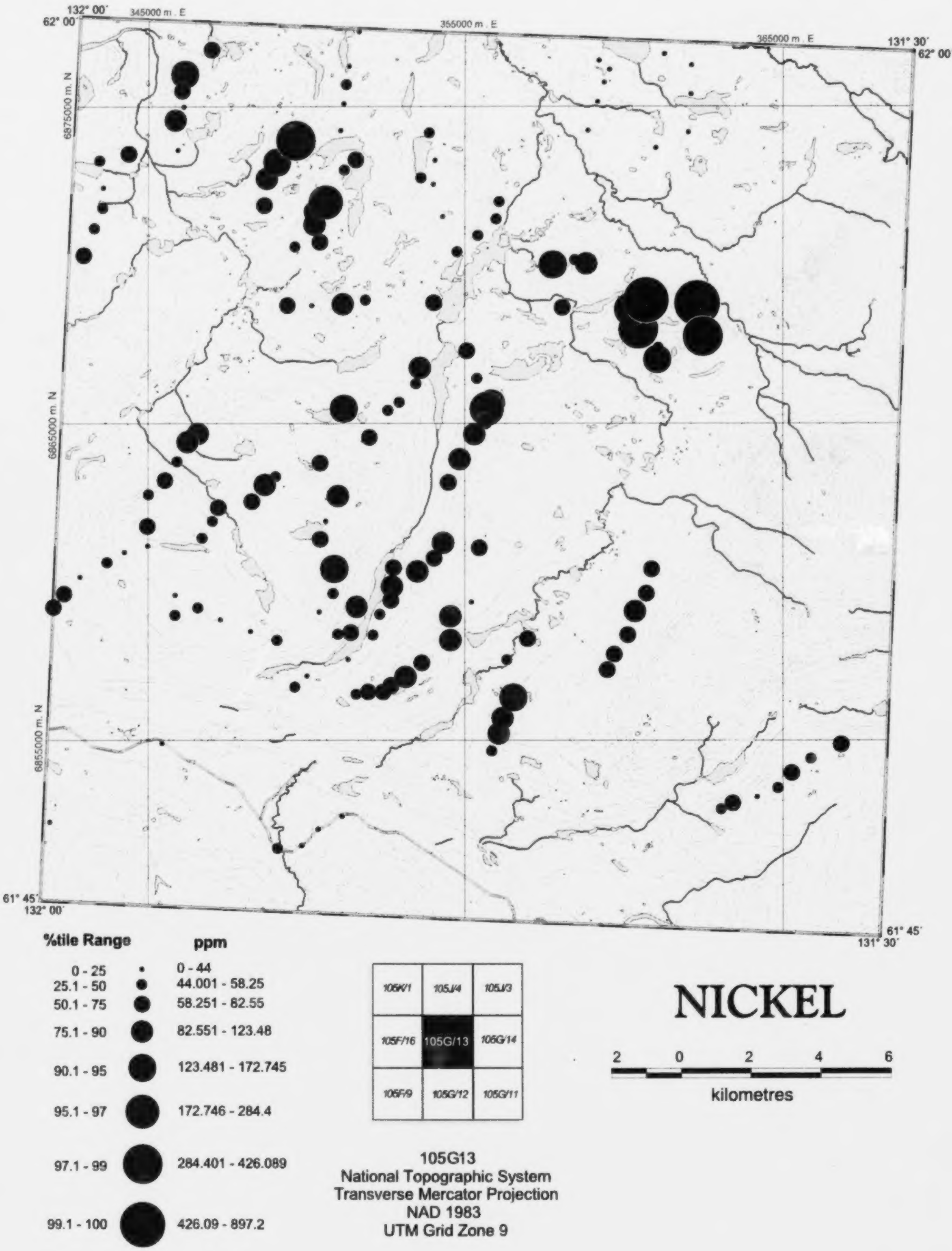
2
4
6
kilometres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345000 m. E
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6875000 m. N
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6855000 m. N
61° 45′
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61° 45′
131° 30′
%tile Range
ppm
0 - 25 • 0 - 44
25.1 - 50 • 44.001 - 58.25
50.1 - 75 ● 58.251 - 82.55
75.1 - 90 ● 82.551 - 123.48
90.1 - 95 ● 123.481 - 172.745
95.1 - 97 ● 172.746 - 284.4
97.1 - 99 ● 284.401 - 426.089
99.1 - 100 ● 426.09 - 897.2
105K/1
105J/4
105J/3
105F/16
105G/13
105G/14
105F/9
105G/12
105G/11
105G13
National Topographic System
Transverse Mercator Projection
NAD 1983
UTM Grid Zone 9
NICKEL
2
0
2
4
6
kilometres

Ancient Pacific Margin – An update on stratigraphic comparison of potential volcanogenic massive sulphide-hosting successions of Yukon-Tanana Terrane, northern British Columbia and Yukon[1]

Maurice Colpron[2]
Yukon Geology Program

and

Yukon-Tanana Working Group[3]

Colpron, M. and Yukon-Tanana Working Group, 2001. Ancient Pacific Margin – An update on stratigraphic comparison of potential volcanogenic massive sulphide-hosting successions of Yukon-Tanana Terrane, northern British Columbia and Yukon. *In:* Yukon Exploration and Geology 2000, D.S. Emond and L.H. Weston (eds.), Exploration and Geological Services Division, Yukon, Indian and Northern Affairs Canada, p. 97-110.

ABSTRACT

Now in its second year, the Ancient Pacific Margin National Mapping (NATMAP) project continues to make progress in elucidating the stratigraphic framework of Yukon-Tanana Terrane of northern British Columbia and Yukon. Updated composite stratigraphic sections for the Finlayson Lake district, Glenlyon, Wolf Lake and Jennings River areas, and from previous studies in the Aishihik Lake area and northern Dawson Range, show that Yukon-Tanana Terrane originated as a dynamic mid- to late Paleozoic (pericratonic) arc system. The evolution of this arc system was punctuated by arc- building events, arc rifting and development of back-arc basins, and episodes of contractional deformation between Late Devonian and early Pennsylvanian. Its development terminated in late Pennsylvanian time with the opening of a marginal basin and the subsequent mid-Permian calc-alkaline volcanism, high-pressure metamorphism and regional deformation of the terrane.

RÉSUMÉ

Dans sa deuxième année, le programme CARTNAT de la marge pacifique ancienne continue ses progrès dans l'élucidation des composantes stratigraphiques du terrane de Yukon-Tanana dans le nord de la Colombie-Britannique et le Yukon. Les révisions des coupes stratigraphiques composées pour les régions de Finlayson Lake, Glenlyon, Wolf Lake et Jennings River (de même que les régions préalablement à l'étude d'Aishihik Lake et de la partie nord du chaînon Dawson) indiquent que le terrane de Yukon-Tanana est dérivé d'un système dynamique d'arc (péricratonique) du Paléozoïque moyen à tardif. Entre le Dévonien tardif et le Pennsylvanien précoce, l'évolution de ce système d'arc fût marqué par des épisodes de construction d'île-en-arc, d'extension de l'arc, d'ouverture de bassins d'arrière-arc, et par des périodes de déformation en contraction. Celà se terminât par l'ouverture d'un bassin marginal au Pennsylvanien tardif et, par la suite, du volcanisme calco-alcalin, du métamorphisme de haute pression, et la déformation régionale du terrane au Permien moyen.

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[1] *Contribution to the Ancient Pacific Margin NATMAP project*

[2] *maurice.colpron@gov.yk.ca*

[3] *Members of the Yukon-Tanana Working Group, their contribution to the Ancient Pacific Margin NATMAP project, affiliations, and contact information are listed in Table 1.*

INTRODUCTION

The Yukon-Tanana Terrane of Yukon, Alaska and northern British Columbia consists of lithologically diverse successions of meta-sedimentary and meta-volcanic rocks, and voluminous mid- and late Paleozoic granitic meta-plutonic bodies (Mortensen and Jilson, 1985; Mortensen, 1992). Significant volcanogenic massive sulphide deposits have been discovered in the terrane in the Delta and Bonnifield districts of Alaska and in the Finlayson Lake district of southeastern Yukon, and the potential for further discoveries is considered to be high. However, exploration for new deposits has been hindered by the

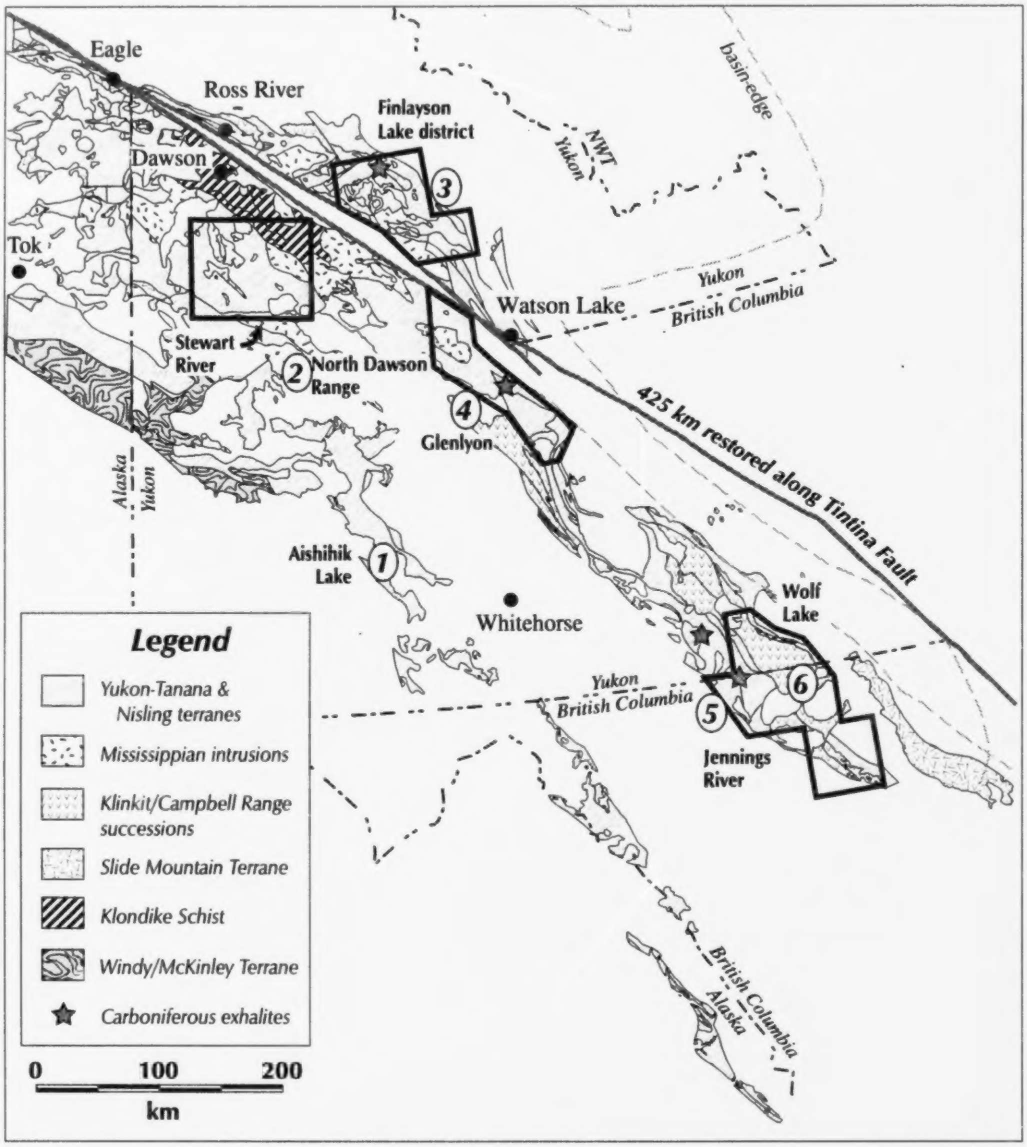
Eagle
Ross River
Finlayson Lake district
Dawson
Tok
NWT
Yukon
basin-edge
3
Watson Lake
Yukon
British Columbia
Stewart River
2
North Dawson Range
4
Glenlyon
425 km restored along Tintina Fault
Alaska
Yukon
Aishihik Lake
1
Whitehorse
Wolf Lake
Yukon
British Columbia
5
6
Jennings River
British Columbia
Alaska
Legend
Yukon-Tanana & Nisling terranes
Mississippian intrusions
Klinkit/Campbell Range successions
Slide Mountain Terrane
Klondike Schist
Windy/McKinley Terrane
Carboniferous exhalites
0
100
200
km

Figure 1. *Distribution of Yukon-Tanana and affiliated terranes (the 'pericratonic' terranes) prior to displacement along Tintina Fault. Areas to be mapped under the auspices of the Ancient Pacific Margin NATMAP Project are indicated. Numbers show the general location of composite stratigraphic columns shown in Figure 2 and discussed in the text: 1) Aishihik Lake; 2) Wolverine Creek, North Dawson Range; 3) Finlayson Lake district; 4) Glenlyon; 5) Northwest Jennings River; 6) South Wolf Lake – North Jennings River. Tectonic assemblage map modified after Wheeler and McFeely (1991).*

paucity of stratigraphic syntheses from the terrane as a whole. One of the goals of the Ancient Pacific Margin NATMAP (National Mapping Program) project is to address the deficiencies in stratigraphic information from the Yukon-Tanana Terrane.

Since inception of the project in 1999, members of the northern component of the Ancient Pacific Margin NATMAP (the Yukon-Tanana Working Group; Table 1; Fig. 1) have advanced the understanding of the stratigraphic framework of Yukon-Tanana Terrane. Sufficient geological mapping and U-Pb dating had been done after the first year to construct composite stratigraphic sections for areas along the extent of southeastern Yukon-Tanana Terrane and to attempt preliminary correlations between the various mapping projects (Nelson et al., 2000). In this paper, we update the composite stratigraphic sections to reflect new geological and geochronological data acquired over the past year and incorporate relevant information from previous studies (Fig. 2).

In 2000, the British Columbia Geological Survey Branch completed their commitment to the mapping of Jennings River area, the Yukon Geology Program continued mapping in the Finlayson Lake district and Glenlyon area, while the Geological Survey of Canada carried on with mapping in the Wolf Lake – Jennings River area and initiated a three-year program in Stewart River area (Fig. 1). The Geological Survey of Canada also flew a multiparameter geophysical survey along a northeast-trending swath over the Stewart River area as part of the Targeted Geoscience Initiative program (R. Shives, in preparation). New stratigraphic information from each of these areas is summarized in the following section.

FINLAYSON LAKE DISTRICT

D.C. Murphy and S.J. Piercey

(Fig. 2, column 3) Yukon-Tanana Terrane in Finlayson Lake map area (105G) and adjacent parts of Frances Lake area (105H; Fig. 1) consists of a number of fault- and/or unconformity-bound stratigraphic successions, some of which host volcanogenic massive sulphide deposits and occurrences (Murphy and Piercey, 1999a; Murphy, this volume; Fig. 2). The Late Devonian to early Pennsylvanian interval is represented by three successions, two in the footwall of the Money Creek thrust (Grass Lakes and Wolverine successions) and one in the hanging wall (un-named); these were juxtaposed in the Pennsylvanian. An un-named Pennsylvanian flysch-like succession

Table 1. *Yukon-Tanana Working Group.*

Geologist	Contribution	Affiliation	Contact
Mitch Mihalynuk JoAnne Nelson	Bedrock mapping – northwest Jennings River Bedrock mapping – central Jennings River	B.C. Geological Survey Branch Ministry of Energy & Mines Victoria, BC V8W 9N3	Mitch.Mihalynuk@gems5.gov.bc.ca Joanne.Nelson@gems1.gov.bc.ca
Steve Gordey Jim Ryan	Bedrock mapping – Stewart River	Geological Survey of Canada Vancouver, BC V6B 5J3	sgordey@gsc.nrcan.gc.ca jryan@nrcan.gc.ca
Charlie Roots	Bedrock mapping – Wolf Lake & Jennings River	Geological Survey of Canada Whitehorse, YT Y1A 2C6	croots@gov.yk.ca
Rob Shives	Multi-parameter geophysics	Geological Survey of Canada Ottawa, ON K1A 0E8	Rshives@nrcan.gc.ca
Rich Friedman Jim Mortensen Steve Piercey	U-Pb geochronology Geochemistry	University of British Columbia Geochronology Laboratory Vancouver, BC V6T 1Z4	rfriedma@eos.ubc.ca jmortensen@eos.ubc.ca Spiercey@eos.ubc.ca
Maurice Colpron Don Murphy	Bedrock mapping – Glenlyon Bedrock mapping – Finlayson & Frances Lake	Yukon Geology Program Whitehorse, YT Y1A 2C6	Maurice.Colpron@gov.yk.ca Don.Murphy@gov.yk.ca
Steve Johnston	Bedrock mapping –Aishihik & Dawson Range	University of Victoria Victoria, BC V8W 3P6	Stj@uvic.ca

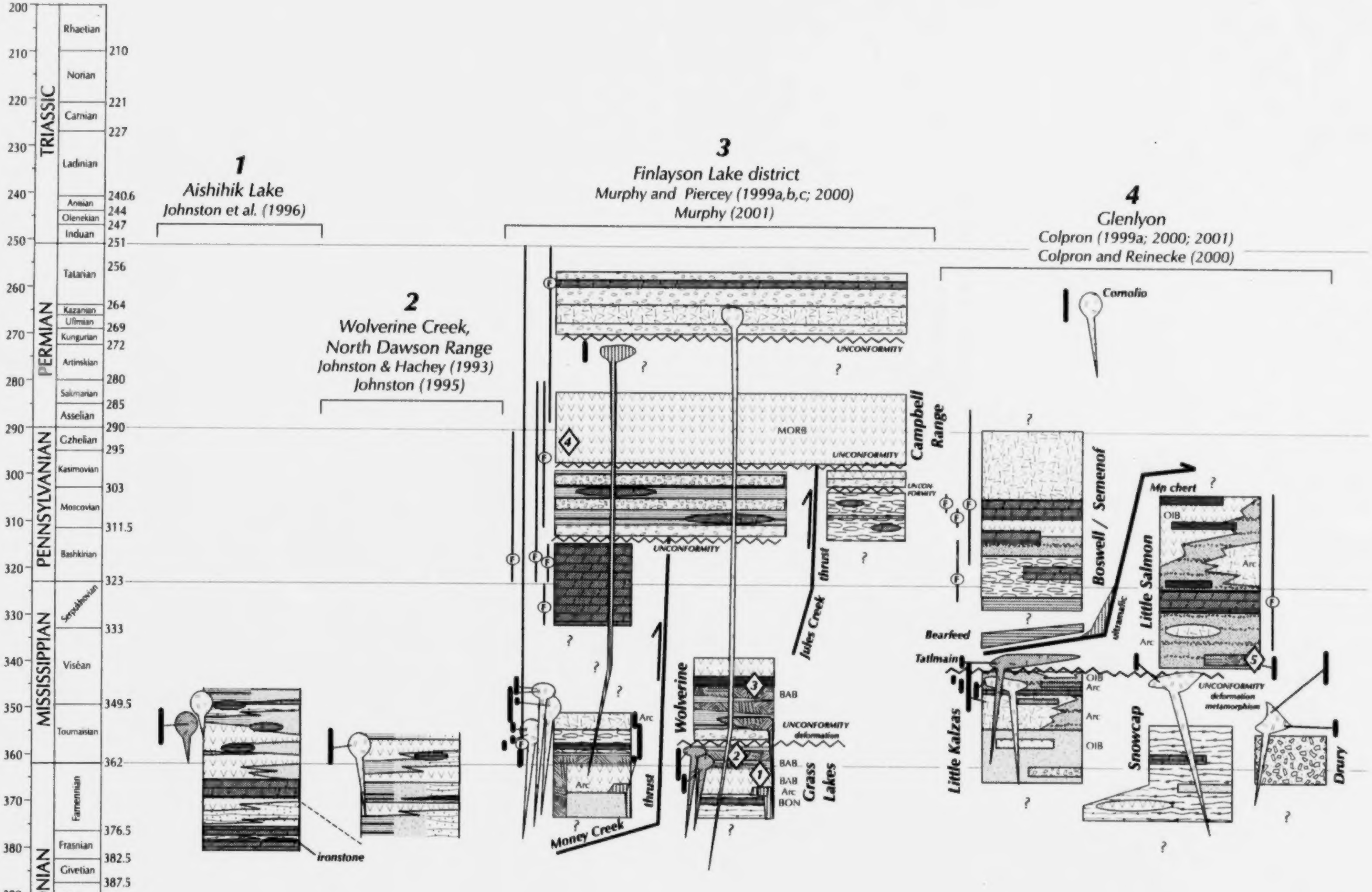
200
210
220
230
240
250
260
270
280
290
300
310
320
330
340
350
360
370
380
390
400
410
420
TRIASSIC
PERMIAN
PENNSYLVANIAN
MISSISSIPPIAN
DEVONIAN
Rhaetian
Norian
Carnian
Ladinian
Anisian
Olenekian
Induan
Tatarian
Kazanian
Ufimian
Kungurian
Artinskian
Sakmarian
Asselian
Gzhelian
Kasimovian
Moscovian
Bashkirian
Serpukhovian
Viséan
Tournaisian
Famennian
Frasnian
Givetian
Eifelian
Dalejan
Emsian
Pragian
Lochkovian
210
221
227
240.6
244
247
251
256
264
269
272
280
285
290
295
303
311.5
323
333
349.5
362
376.5
382.5
387.5
394
409
413
418
1
Aishihik Lake
Johnston et al. (1996)
2
Wolverine Creek,
North Dawson Range
Johnston & Hachey (1993)
Johnston (1995)
3
Finlayson Lake district
Murphy and Piercey (1999a,b,c; 2000)
Murphy (2001)
4
Glenlyon
Colpron (1999a; 2000; 2001)
Colpron and Reinecke (2000)
ironstone
UNCONFORMITY
MORB
Campbell Range
UNCONFORMITY
Money Creek
thrust
Arc
Wolverine
BAB
UNCONFORMITY deformation
BAB
BAB
Arc
BON
Grass Lakes
Jules Creek thrust
Comolio
Boswell / Semenof
Mn chert
OIB
Arc
Little Salmon
Bearfeed
Tatlmain
ultramafic
Little Kalzas
OIB
Arc
Arc
OIB
Snowcap
UNCONFORMITY deformation metamorphism
Drury
1
2
3
4
5
?

Figure 2. Composite stratigraphic columns for areas discussed in the text and located on Figure 1. Mineral occurrences: 1 – Fyre Lake deposit; 2 – Kudz Ze Kayah and GP4F deposits; 3 – Wolverine deposit; 4 – Money occurrence; 5 – Government showing; 6 – Cabin Lake and Cariboo Creek occurrences; 7 – Arsenault occurrence. Petrogenetic affinity of the volcanic successions is indicated where known: Arc = island arc; BAB = back-arc basin; BON = boninite; MORB = mid-ocean ridge basalt; OIB = ocean island basalt. (A coloured version of this diagram can be downloaded at www.geology.gov.yk.ca/publications/yeg00/YTTcorrelations2001.pdf)

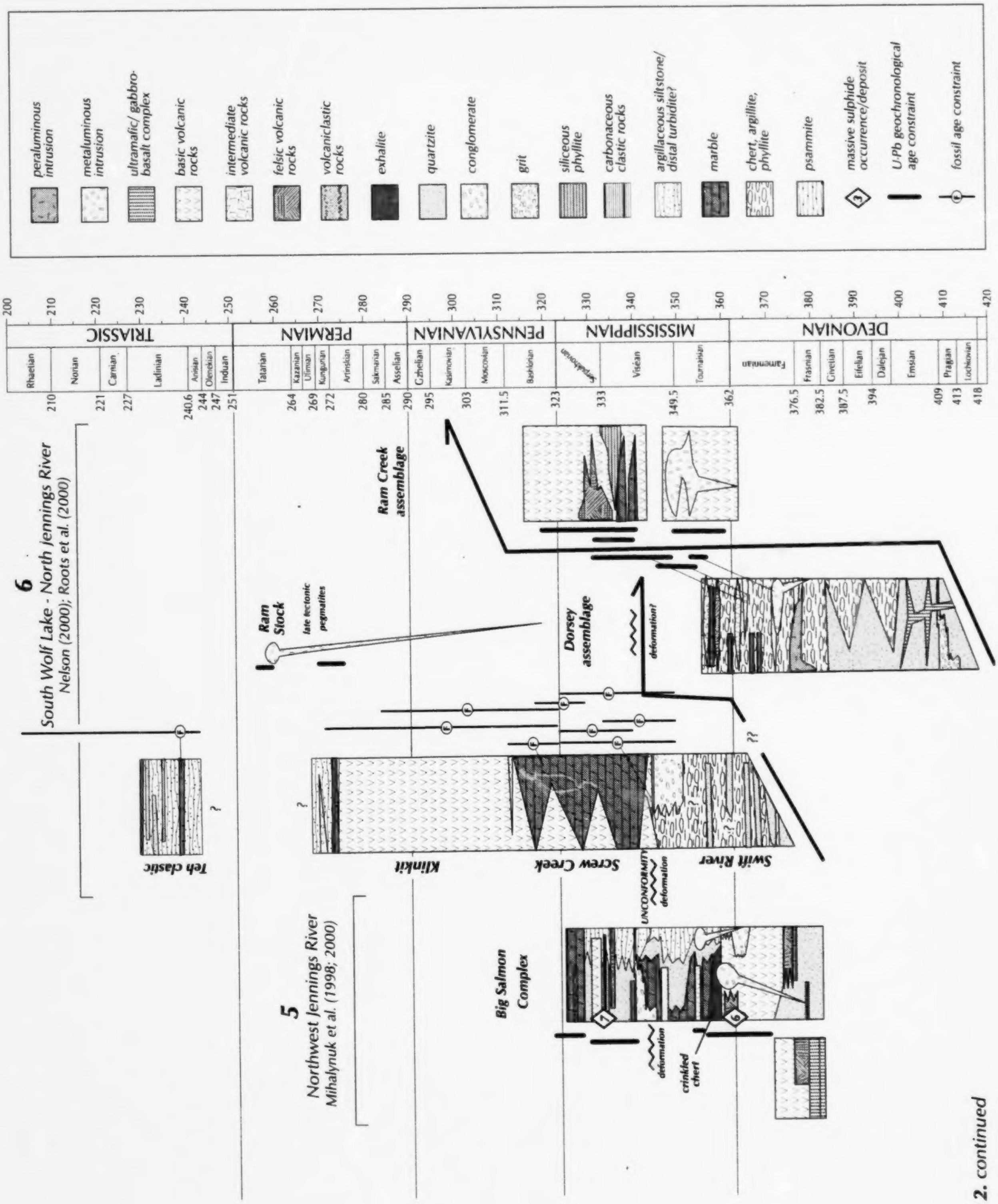
peraluminous intrusion
metaluminous intrusion
ultramafic/ gabbro-basalt complex
basic volcanic rocks
intermediate volcanic rocks
felsic volcanic rocks
volcaniclastic rocks
exhalite
quartzite
conglomerate
grit
siliceous phyllite
carbonaceous clastic rocks
argillaceous siltstone/ distal turbidite?
marble
chert, argillite, phyllite
psammite
massive sulphide occurrence/deposit
U-Pb geochronological age constraint
fossil age constraint
TRIASSIC
PERMIAN
PENNSYLVANIAN
MISSISSIPPIAN
DEVONIAN
Rhaetian
Norian
Carnian
Ladinian
Anisian
Olenekian
Induan
Tatarian
Kazanian
Ufimian
Kungurian
Artinskian
Sakmarian
Asselian
Gzhelian
Kasimovian
Moscovian
Bashkirian
Serpukhovian
Viséan
Tournaisian
Famennian
Frasnian
Givetian
Eifelian
Dalejan
Emsian
Pragian
Lochkovian
200
210
220
230
240
250
260
270
280
290
300
310
320
330
340
350
360
370
380
390
400
410
420
210
221
227
240.6
244
247
251
264
269
272
280
285
290
295
303
311.5
323
333
349.5
362
376.5
382.5
387.5
394
409
413
418
6
South Wolf Lake - North Jennings River
Nelson (2000); Roots et al. (2000)
Teh clastic
?
Ram Stock
late tectonic pegmatites
Ram Creek assemblage
Dorsey assemblage
deformation?
Klinkit
Screw Creek
UNCONFORMITY
deformation
Swift River
??
5
Northwest Jennings River
Mihalynuk et al. (1998; 2000)
Big Salmon Complex
7
6
deformation
crinkled chert

Figure 2. continued

unconformably overlaps the Money Creek thrust. This succession and subjacent rocks are in turn thrust over a probably Pennsylvanian succession along the Jules Creek thrust, which is in turn overlapped by late Pennsylvanian to Early Permian meta-basalt of the Campbell Range succession. An unconformably overlying polymictic conglomerate of probable mid-Permian age records an Early Permian history of arc magmatism, high-pressure metamorphism, uplift and erosion.

The Grass Lakes and Wolverine successions in the footwall of the Money Creek thrust record two phases of Late Devonian to early Mississippian continental arc and back-arc magmatism and sedimentation separated by an unconformity marking a period of deformation, uplift and erosion. The base of the Grass Lakes succession, and basement to the magmatic arc/back-arc system, comprises pre-Upper Devonian quartz-rich meta-clastic rocks, marble and pelitic schist. The initial magmatic deposits consist of Upper Devonian to lower Mississippian mafic schist, host of the Fyre Lake Cu-Co-Au deposit, with lesser amounts of carbonaceous meta-clastic rock, felsic meta-volcanic and -volcaniclastic rock, and marble. Geochemically, these rocks range from boninite - low Ti tholeiite and calc-alkaline arc suites to non-arc mid-ocean ridge basalts (MORBs) and Nb-enriched basalt, suggesting an early arc history followed by rifting. These rocks pass upward into early Mississippian massive sulphide-bearing (Kudz Ze Kayah and GP4F; Cu-Pb-Zn-Au-Ag bearing), high-field-strength-element-enriched (A-type; Whelan et al., 1987), felsic meta-volcanic and -volcaniclastic rocks, and carbonaceous phyllite that probably reflect an ongoing evolution toward a back-arc basin environment. The upper unit of the Grass Lakes succession consists of early Mississippian carbonaceous phyllite, quartzite, quartz-feldspar pebble meta-conglomerate and alkalic mafic schist. The Grass Lakes succession was intruded by early Mississippian peraluminous granitic meta-plutonic rocks, deformed, and re-intruded by slightly younger, late-kinematic, early Mississippian granitic meta-plutonic rocks, before the unconformable deposition of the Wolverine succession. Also of early Mississippian age, the Wolverine succession comprises mainly carbonaceous meta-clastic rocks, felsic schist and quartz-feldspar meta-porphyry of volcanic, volcaniclastic and subvolcanic intrusive protolith. A laterally persistent unit of exhalite-bearing, felsic meta-volcanic and -volcaniclastic rocks, and carbonaceous argillite caps the felsic meta-volcanic part of the succession, in the immediate hanging wall of the Wolverine Cu-Pb-Zn-Au-Ag massive sulphide deposit. Felsic meta-volcanic rocks are transitionally overlain by a meta-basalt member that is locally preserved beneath the unconformably overlying Pennsylvanian flysch. Geochemically, felsic rocks below the Wolverine deposit are A-type rhyolites similar to those in the Grass Lake succession whereas those above the deposit are lower in Zr, possibly reflecting a lower temperature of formation.

The Grass Lakes and Wolverine successions were overridden from the southwest by coeval volcanic-arc rocks, their subvolcanic intrusions and early Pennsylvanian bioclastic limestone along the Money Creek thrust. Although incompletely mapped, the lower part of the thrust sheet comprises island-arc tholeiitic and calc-alkaline basalt, basaltic andesite and lesser rhyolite, limestone, chert and dark argillite. These pass upward into intermediate to felsic meta-volcanic rocks (chloritic phyllite, muscovite-quartz phyllite and foliated rhyodacitic tuff breccia). Several calc-alkaline granodiorite to granite plutons of the early Mississippian Simpson Range plutonic suite intrude the stratified rocks. A laterally persistent crinoidal limestone of probable early Pennsylvanian age overlies the meta-volcanic rocks with sharp contact. Bedded barite and massive-sulphide-style prospects have been identified in the meta-volcanic rocks of the Money Creek thrust sheet. Plutons of the Simpson Range plutonic suite are locally altered and copper-stained, suggesting a potential for porphyry-style mineralization.

Both the hanging wall and footwall of the Money Creek thrust are overlain by a dark heterogeneous coarse clastic unit of probable Pennsylvanian age. This unit is composed of carbonaceous argillite, chert (mainly dark but also locally pink, tan and green), chert-pebble conglomerate, greywacke, volcano-lithic conglomerate, limestone-pebble conglomerate (mainly at base), diamictite (made up of pebble- to boulder-sized clasts of meta-volcanic and meta-sedimentary rocks in either an argillite or greywacke matrix) and rare quartz sandstone and limestone. As this dark clastic unit overlies both the hanging wall and footwall of the Money Creek thrust and is not displaced by the thrust, its probable Pennsylvanian age places an upper constraint on the age of the Money Creek thrust.

The rocks of the Money Creek thrust sheet and the unconformably overlying dark clastic unit are thrust to the northeast along the Jules Creek thrust. The footwall succession comprises a lower unit similar to the dark heterogeneous clastic unit, an unconformably overlying post-tectonic conglomerate and an upper unit of meta-basalt. The lower unit is predominantly dark argillite and chert, with lesser chert-pebble conglomerate and pink and green chert. It differs from the dark heterogeneous clastic unit in the scarcity of coarse-grained volcano-lithic clastic rocks. Only one metre-scale bed of greywacke was observed. Post-tectonic conglomerate overlies the lower unit, and its basal strata comprise angular breccia, made up of randomly oriented foliated clasts of the lower unit. The post-tectonic conglomerate is overlain with sharp contact by a variably foliated meta-basalt unit that resembles the Campbell Range basalt described below.

Late Pennsylvanian to Early Permian Campbell Range basalt overlies both the hanging wall and footwall of the Jules Creek thrust. As the basalt is not offset, displacement on the Jules Creek thrust was probably late Pennsylvanian in age. The Money volcanic-hosted massive sulphide prospect and numerous areas with anomalous Cu soil geochemistry occur in the Campbell Range basalt.

The eastern slopes of the Campbell Range are underlain by a heterolithic pebble to boulder conglomerate that, based on clast content, probably unconformably overlies older rocks of Yukon-Tanana Terrane. In addition to clasts derived from the above-described rock units, the conglomerate contains clasts of Permian arc-volcanic rocks, and blueschist and eclogite with Permian cooling ages (Mortensen et al., 1999). Although these types of rocks are found *in situ* elsewhere in Yukon-Tanana Terrane, they only occur as clasts in the Finlayson – Frances Lake area. The proximal nature of the conglomerate, however, suggests a nearby source.

GLENLYON AREA

M. Colpron

(Figure 2, column 4) Ongoing geological mapping and geochronological studies have led to the identification of distinct stratigraphic successions and two Mississippian magmatic suites within Yukon-Tanana Terrane of Glenlyon map area (Fig. 1). In the northwest, early to mid-Mississippian (343-346 Ma; Colpron et al., 2000) volcanic rocks of the Little Kalzas succession, which consist predominantly of plagioclase-phyric andesite, volcaniclastic rocks, and subordinate marble, rhyolite and alkali basalt, conformably overlie orthoquartzite of the Pelmac unit (Fig. 2; Colpron, 1999a). Geochemistry of volcanic rocks from the Little Kalzas succession suggests that they formed in a continental arc setting (Colpron, this volume). The Pelmac unit rests structurally above amphibolite-grade meta-sedimentary and meta-igneous rocks of uncertain age, which are found in central Glenlyon map area (units 6 b-c of Campbell, 1967; U. Schmidt, pers. comm., 1999). The Pelmac unit and overlying Little Kalzas succession (and subvolcanic intrusions of the Little Kalzas suite) were deformed by south-verging folds and metamorphosed to greenschist facies prior to the intrusion of the Tatlmain Batholith at ~340 Ma (Colpron et al., 2000).

In southeast Glenlyon, mid-Mississippian to early Pennsylvanian volcanic rocks of the Little Salmon succession unconformably overlie two distinct map units (Fig. 2; Colpron and Reinecke, 2000). To the east, the Little Salmon succession rests above the Drury unit, an arkosic grit and quartzite unit, which is intruded by an early Mississippian granodiorite. To the west, the volcanic rocks overlie a mixture of meta-sedimentary and meta-igneous rocks, which record a poly-metamorphic history – the Snowcap assemblage (Colpron, 2000). These rocks are intruded by diorite plutons of the Tatlmain/Little Salmon suite (ca. 340 Ma), which are likely subvolcanic to the Little Salmon succession. Accordingly, the Snowcap assemblage forms the basement onto which volcanic rocks of the Little Salmon succession were erupted. The relationship between the Snowcap assemblage and similar metamorphic rocks in central Glenlyon is unknown. They may be part of the same lithotectonic assemblage.

The Little Salmon succession is dominated by volcaniclastic rocks (both epiclastic and tuffaceous; Colpron and Reinecke, 2000). A prominent marble unit of late Mississippian – early Pennsylvanian age (E.W. Bamber *in:* Colpron and Reinecke, 2000) occurs in the lower part of the Little Salmon succession. Dacite and quartz-feldspar porphyry, dated at ca. 340 Ma (Colpron et al., 2000), mark the base of the sequence near Little Salmon Lake. The felsic volcanic unit hosts a small sulphide occurrence (Colpron, 1999b). Near Little Salmon Lake, volcanic rocks of the Little Salmon succession are typically of calc-alkaline composition; they record a second cycle of continental arc magmatism in the area (Colpron, this volume). These rocks pass along strike to the northwest into a sequence of alkali basalt, which contains manganiferous exhalative rocks (piedmontite chert; Colpron, this volume).

Both the Little Kalzas and Little Salmon successions have mixed calc-alkaline (Arc = island arc) and alkaline (OIB = ocean island basalt) geochemical signatures (Fig. 2). In the Little Kalzas succession, alkali basalt both underlies and overlies the calc-alkaline volcanic rocks. In Little Salmon succession, alkali basalt appears to be laterally continuous with the calc-alkaline andesite. The occurrence of alkaline rocks within continental arc sequences of Yukon-Tanana Terrane is most reasonably interpreted to indicate episodic rifting of the arc (Colpron, this volume). It is also noteworthy that the two main pulses of arc magmatism documented here are punctuated by an episode of contractional deformation (Colpron et al., 2000).

The Boswell/Semenof succession is juxtaposed with the Snowcap assemblage along Big Salmon Fault (Colpron, this volume). This succession consists of dark grey slate, greywacke and chert-pebble conglomerate, limestone, volcaniclastic rocks and andesitic greenstone of Pennsylvanian age (Fig. 2; Tempelman-Kluit, 1984; Tempelman-Kluit *in:* Gordey et al., 1991; Poulton et al., 1999). Although it is not currently considered part of Yukon-Tanana Terrane (Wheeler et al., 1991 included it in Slide Mountain Terrane; Gordey and Makepeace, 1999, in Quesnel Terrane), the resemblance of Boswell/Semenof succession to recently identified Pennsylvanian strata in Yukon-Tanana Terrane of Finlayson Lake district (Murphy, this volume; Fig. 2, column 3) requires a re-evaluation of its tectonic setting. Dark grey siliceous phyllite (and subordinate graded sandstone, conglomerate and marble) of the Bearfeed allochthon, which sits in klippen overlying the Little Salmon succession (Colpron, 2000), is possibly correlative with the base of the Boswell/Semenof succession.

SOUTHERN WOLF LAKE – NORTHERN JENNINGS RIVER AREA

J.L. Nelson and C.F. Roots

(Fig. 2, column 6) This set of three sections represents all of the allochthonous (non-North American) rocks in the Wolf Lake/Jennings River area (Fig. 1), with the exception of the Big Salmon Complex. From east to west, the three columns represent: the Ram Creek assemblage, the Dorsey assemblage, and a stratigraphic composite that includes the Swift River succession, Screw Creek limestone and Klinkit succession.

The Ram Creek assemblage contains tracts of mafic to rhyolitic meta-tuffs with local limestone and chert sequences. Two U-Pb dates from felsic tuffs are late Mississippian (Nelson, 2000), coeval with tuffs in the Big Salmon Complex (Figure 2, column 5) and Little Salmon succession (Figure 2, column 4). One metaplutonic body within the Ram Creek assemblage is of early Mississippian age (Nelson, 2000); in another, the U-Pb systematics allow for either an early or a late Mississippian age (Roots and Heaman, 2001).

The Dorsey assemblage structurally overlies the Ram Creek assemblage across an east-verging, post-mid Permian but pre-Early Jurassic thrust fault (Stevens and Harms, 1995; Stevens and Harms, 2000). The Dorsey assemblage is a siliceous succession including quartzite and quartzo-feldspathic meta-sedimentary protoliths, intermediate to mafic meta-tuff, meta-chert, quartz-augen felsic meta-tuff and marble; meta-basic bodies (amphibolite/garnet amphibolite) are concentrated near its base. Highly deformed early Mississippian granitoids range from granite to gabbro. The Dorsey assemblage is characterized by medium- to high-pressure metamorphic mineral assemblages, where they have not been obscured by retrograde overprinting. The oldest rocks in it are pre-early Mississippian, and could be much older. A quartz-augen meta-rhyolitic tuff in the upper part of the Dorsey assemblage in southern Yukon has yielded an early Mississippian U-Pb age (Roots and Heaman, 2001). This lends strength to the argument, based on dated granitoids, that the Dorsey assemblage represents an early Mississippian arc and its pericratonic substrate. The rhyolite is highly foliated to protomylonitic, and contains microcline, relict coarse muscovite and rare garnets. Its state of strain and degree of metamorphism are indistinguishable from the rocks that surround it. Thus the major deformation/metamorphism of this assemblage was probably between early Mississippian and mid-Permian, the age of the post-kinematic Ram stock that intrudes the Dorsey assemblage in southern Yukon (Stevens and Harms, 1995).

West of, and structurally above the metamorphic Dorsey assemblage, three units occur in a folded but consistent stratigraphic sequence. The lowest of these, the Swift River succession, comprises dark-coloured chert and argillite with interbeds and intervals of quartzite, greywacke and quartz-feldspar grit. It overlies the Dorsey assemblage on a contact that is sharp to gradational in terms of lithology, and gradational in metamorphic grade: garnet and biotite persist upwards into the lowest Swift River rocks. The oldest age of the Swift River succession is unknown. It is stratigraphically overlain by the Screw Creek limestone, which contains mid-Mississippian (Viséan) as well as Pennsylvanian fossils. Evidence that this contact is a regional late Mississippian unconformity is as follows: 1) Locally the uppermost part of the Swift River succession consists of pebble- to boulder-conglomerate with chert, argillite and quartzite clasts, and a grit-greywacke-rich sequence. 2) The Screw Creek limestone contains layers of chert pebbles, presumably derived from the underlying Swift River succession, as well as volcanic debris that links it to the overlying/ interfingering Klinkit succession. 3) Finally, in the northern part of the area, the Swift River succession is eliminated, and undated but probable Screw Creek-equivalent limestone, and associated volcanic rocks of the Klinkit succession, lie directly above the Dorsey assemblage.

The Klinkit succession has two distinct facies. A volcanic/ epiclastic facies dominates most of the area, containing green chloritic meta-tuffs and breccias, volcanic-derived meta-siltstone and minor mafic flows, light-coloured limestone and siltstone-argillite layers. This widespread volcanogenic sequence occurs from west-central Wolf Lake map area in the north, through Swift River/ McNaughton Creek and into west-central Jennings River map area south of the Simpson Peak batholith. A much more restricted facies only outcrops west of the Seagull Batholith. There, the Screw Creek limestone is overlain by an unusual non-volcanic quartz-clastic sequence, characterized by thin-bedded limy siltstone and argillite, with black chert intervals.

The top of the Klinkit succession in west-central Jennings River area is a variable succession of meta-siltstone through quartzite with chloritic meta-tuff layers. The youngest unit, the Triassic 'Teh clastic' succession, consists of interbedded black argillite, meta-siltstone and quartzite, with minor chert, fetid limestone and conglomerate (T. Harms, pers. comm., 1999). Three limestone localities yielded Triassic conodont fauna (M. Orchard, pers. comm. to T. Harms, 1997). The 'Teh clastic' succession overlies a variety of units. North of Klinkit Lake, it appears to conformably overlie a 70-m-thick succession of mixed limestone, mafic to intermediate volcaniclastics and minor argillite. This succession in turn overlies the main volcanogenic Klinkit succession. However, in at least one locality, between the southern lobes of the Simpson Peak and Nome Lake batholiths, it directly overlies metamorphosed and multiply foliated Swift River succession phyllites in a presumed unconformable relationship.

NORTHWEST JENNINGS RIVER AREA

M.G. Mihalynuk

(Fig. 2, column 5) In 2000, fieldwork in northwest Jennings River (Fig. 1) focused on examination of a manganiferous meta-chert marker horizon within the Big Salmon Complex referred to as the 'crinkle chert' (Mihalynuk et al., 1998). This marker can be traced for over 80 km in northern British Columbia. It is lithologically similar to a unit known from the Little Salmon area (Colpron and Reinecke, 2000), 250 km to the north, but geological evidence indicates that the two are probably not coeval. The maximum age of the Little Salmon Mn-chert is constrained as late Mississippian by the maximum age limit of fossils in underlying strata (Fig. 2, column 4). On the other hand, the minimum age of the Big Salmon Complex crinkle chert is older than middle Mississippian, based on dykes that cut overlying strata (Mihalynuk et al., 2000).

Prior to 2000, it was not possible to unambiguously establish the origin of the crinkle chert on field evidence alone. It could be interpreted as a pure meta-siltstone, but it lacks clastic sedimentary textures. It could be metamorphosed radiolarian chert that lacks fossil radiolaria because of the high degree of strain to which the unit has been subjected.

Field investigations in 2000, however, revealed stratiform magnetite layers near the top of the crinkle chert unit. These layers, up to a decimetre thick, are best explained as hydrothermal in origin. Furthermore, evaluation of existing geochemical data from the crinkle chert also indicates a hydrothermal, not hydrogenous genesis (Mihalynuk and Peter, 2001). A seafloor hydrothermal source for the crinkle chert unit underscores the potential for volcanogenic massive sulphide mineralization in the area.

AISHIHIK LAKE AREA

S.T. Johnston

(Fig. 2, column 1) The Aishihik metamorphic suite (Erdmer, 1991) is commonly included in Nisling Terrane (Gordey and Makepeace, 2000), but is here considered part of Yukon-Tanana Terrane. It occurs outboard (west) of accreted oceanic and oceanic-arc terranes (Stikinia and Cache Creek) in southwest Yukon (Fig. 1). The suite is penetratively deformed and metamorphosed, having experienced regional synkinematic metamorphism ($P < 10$ kbar) in the early Jurassic, and high T – low P metamorphism associated with the emplacement of the Ruby Range plutonic suite in the latest Cretaceous and early Tertiary.

The Aishihik suite is divisible into two units, and dips regionally to the northeast, exposing the structurally deepest rocks to the southwest. The younging direction of the suite is unknown. A structurally lower unit of feldspathic quartz-mica schist and marble, with minor mafic and felsic meta-volcanic rocks, is locally characterized by ironstone (magnetite) lenses. The marble horizons form continuous layers (up to 50 m thick) that can be traced for kilometres. The heterogeneous upper unit consists of equal volumes of clastic sedimentary and igneous rocks, and is commonly separated from the lower unit by a conspicuous marble – amphibolite layer >1 km thick. Carbonaceous quartzite, micaceous quartzite, and discontinuous lenses of marble are intimately interfoliated with meta-igenous rocks comprising thick sequences of mafic to intermediate volcanic rocks, and both I- and S-type granitoid intrusions.

The Aishihik metamorphic suite is intruded by, and is older than, the Aishihik Batholith (U-Pb zircon age of 185.6 +2.0 / -2.4 Ma). A U-Pb zircon age determination of a sample of a two-mica, peraluminous orthogneiss from the Upper Aishihik metamorphic suite is consistent with crystallization between 351.5 ± 2.0 and 343.8 ± 0.8 Ma (inheritance and lead loss prevent a more precise age determination). Because the igneous rocks in the upper unit appear to be intimately interlayered with the clastic rocks, pointing to an original depositional relationship, we interpret this age to be close to the age of the associated sedimentary rocks. Both the Aishihik Batholith and the two-mica orthogneiss are characterized by an inherited zircon component with a Paleoproterozoic average age (Johnston et al., 1996).

NORTHERN DAWSON RANGE

S.T. Johnston

(Fig. 2, column 2) A heterogeneous mix of carbonaceous clastic and meta-igneous rocks with minor marble and calc-silicate rocks (Johnston and Hachey, 1993) occurs as wall rocks to, and xenoliths and septa within the mid-Cretaceous Dawson Range Batholith. The younging direction of this suite is unknown. The structurally lowest portions of the suite consist of thick sections of carbonaceous to tan quartzite. These pass up section into a more igneous dominated sequence. Minor amounts of felsic schist and amphibolite are interlayered with quartz-mica schist, quartzite, discontinuous lenses of marble, and large volumes of metaluminous orthogneiss interpreted as intrusions. These include the Selwyn gneiss, which caps the sequence to the northeast. The suite is definitely older than the 105 Ma Dawson Range Batholith and also intruded by probable Early Jurassic plugs. A U-Pb zircon age of 357.9 ± 3.5 (Johnston, 1995; S. Johnston and J. Mortensen, unpublished data, 1995) for a sample of orthogneiss interpreted as an intrusive body, may provide a minimum age constraint for the metaclastic and metavolcanic rocks in northern Dawson Range.

STEWART RIVER AREA

J.J. Ryan and S.P. Gordey

Geological mapping during the summer of 2000 near Thistle Creek represents the first of a three-year program in the Stewart River area (115N-O). Because this project is in its early stage, the lack of geochronological and/or paleontological constraints, and uncertainties as to the stratigraphic younging of these rocks preclude inclusion of a stratigraphic column for Yukon-Tanana Terrane in the Stewart River area. What follows is a brief discussion of the tectonostratigraphic associations identified in the Thistle Creek area (115O/3); more detailed descriptions of these rocks are given in Ryan and Gordey (2001a; 2001b).

Yukon-Tanana Terrane in the Thistle Creek area comprises polydeformed and metamorphosed amphibolite facies gneisses and schists intruded by younger plutonic rocks. The gneisses exhibit a shallowly inclined, high-strain regional foliation (S_T), formed through transposition of bedding (S_0), unit contacts, an earlier foliation (S_1?), and minor veins. Regional correlations of plutonic suites indicate that the transposition event was post-Carboniferous and pre-Jurassic (Mortensen 1992). Although primary stratigraphy is obscured by the transposition as well as by later open folds and faults, the area is clearly dominated by two fault-bounded tectonostratigraphic associations: 1) polyphase grey orthogneiss in garnet-amphibolite schist/gneiss, interpreted herein as a meta-volcano-plutonic complex; 2) interstratified garnet-amphibolite schist/gneiss and meta-sedimentary schist and paragneiss derived from psammite, semipelite and quartz arenite, collectively interpreted as a meta-volcano-sedimentary succession.

Amphibolites, which are the most widespread rock type, have been intensely tectonized. Heterogeneous compositional layering and local vestiges of primary textures such as breccia clasts or pillow selvages indicate derivation from mafic volcanic to volcaniclastic rocks. Quartz-sericite schist, likely derived from felsic volcanic rocks or hypabyssal intrusions, are locally interlayered with the amphibolites. The interfingered meta-felsites and amphibolites are consistent with bimodal volcanism, possibly in an arc setting.

Grey and white-banded quartzites are generally in fault contact with the gneisses and schists, and their stratigraphic relationships are equivocal. An occurrence of meta-conglomerate along the Yukon River exhibits quartz and tonalite clasts in a matrix of quartzofeldpathic schist. The conglomerate grades locally to impure quartz arenite, and is adjacent to an occurrence of grey quartzite.

Three bodies of potassic feldspar augen granite gneiss in Thistle Creek map area may correlate with a suite of Devono-Mississippian augen granites dated regionally at ca. 360 Ma (Mortensen, 1992). These have experienced complete transposition deformation. Young, leucocratic granitic plutons and/or dykes crosscut the gneisses. Some carry a weak foliation in their margins, and others exhibit weak boudinage. A pluton and several smaller satellite bodies and dykes in the central part of the map area consist of syenogranite with large potassic feldspar phenocrysts. They are completely undeformed, and are likely Cretaceous or younger. Rare young, quartz-potassic feldspar porphyritic rhyolite to rhyodacite stocks in the area are of probable Tertiary age.

Recognition of the Thistle Creek area as containing abundant meta-volcanic rocks has significant implications for its economic potential. The few occurrences of felsic schist in the area may be prospective for syngenetic mineralization (both Kudz Ze Kayah and Wolverine deposits are hosted in felsic volcanic rocks; Murphy, 1998 and references therein). Exploration will have to take into account that primary geochemical (e.g., alteration), structural and lithological signatures have been strongly modified by the high metamorphic grade and state of strain.

SUMMARY

The integration of stratigraphic, structural, geochronological and geochemical data depicts the Yukon-Tanana Terrane as a dynamic mid- to late Paleozoic pericratonic arc/back-arc system. Episodic magmatism prevailed in most parts of the terrane between Late Devonian and early Pennsylvanian time. During this period, the terrane experienced multiple cycles of arc build-up, arc rifting and the development of back-arc basins. It is near the end of two such cycles that the rich, polymetallic Kudz Ze Kayah and Wolverine deposits were formed in the Finlayson Lake district. In other parts of the terrane, hydrothermal activity is indicated by the occurrence of manganiferous siliceous exhalites (e.g., the 'crinkle chert' marker in the Big Salmon complex) and numerous base-metal occurrences (Fig. 2).

These arc/back-arc cycles were punctuated by episodes of apparently contractional deformation. The oldest deformational event, of early Mississippian age, separates the two magmatic cycles identified in the Finlayson Lake district. A younger, mid-Mississippian episode of contractional deformation, first identified in northwest Glenlyon area, may well have affected much of the southern Yukon-Tanana Terrane (Fig. 2). This deformational event closely follows the cooling of eclogites at 346 Ma in the terrane in Frances Lake area (Erdmer et al., 1998). At least two additional episodes of northeast-directed thrusting are inferred to have occurred during Pennsylvanian time in the Finlayson Lake district; these events have not yet been recognized elsewhere in the terrane.

Late Mississippian – early Pennsylvanian time was a period of significant carbonate deposition in Yukon-Tanana Terrane. By late Pennsylvanian time, much of the terrane was overlain by basic volcanic rocks of the Campbell Range, Semenof and Klinkit successions. These rocks represent the most definite tie between the various parts of the terrane. They probably record the development of a marginal basin, which may have persisted into Early Permian time.

By mid- to Late Permian time (ca. 270-260 Ma), a magmatic arc developed in the Klondike region (Klondike Schist; Mortensen, 1990), while other parts of Yukon-Tanana Terrane were undergoing regional deformation and high-pressure metamorphism (e.g., Erdmer et al., 1998). The record of these events is in part preserved in the Permian conglomerate, which unconformably overlies Yukon-Tanana Terrane in Finlayson Lake, Frances Lake and Watson Lake areas. Mid-Permian metaluminous plutons elsewhere in the terrane (Cornolio pluton, Ram stock, and small intrusions in Finlayson Lake district; Fig. 2) are likely the southern extent of the Klondike magmatic arc.

Work continues in documenting the stratigraphic successions and in characterizing the volcanic sequences of Yukon-Tanana Terrane. These data will also be compiled on a common base (with the Tintina Fault restored) with the objective of constructing a set of paleogeographic maps for the Paleozoic of Yukon-Tanana Terrane. These maps will identify what geological environments were operative at different times in the evolution of the terrane and highlight areas where information is lacking. Furthermore, documentation of the various geological environments represented in Yukon-Tanana Terrane will assist in identifying regions which may be prospective for deposition of syngenetic sulphide deposits in this and correlative parts of the Canadian Cordillera.

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Geochemical characterization of Carboniferous volcanic successions from Yukon-Tanana Terrane, Glenlyon map area (105L), central Yukon[1]

Maurice Colpron[2]
Yukon Geology Program

Colpron, M., 2001. Geochemical characterization of Carboniferous volcanic successions from Yukon-Tanana Terrane, Glenlyon map area (105L), central Yukon. *In:* Yukon Exploration and Geology 2000, D.S. Emond and L.H. Weston (eds.), Exploration and Geological Services Division, Yukon, Indian and Northern Affairs Canada, p. 111-136.

ABSTRACT

Detailed mapping of Yukon-Tanana Terrane in Glenlyon map area has identified two Carboniferous volcanic successions, and their subvolcanic intrusions. The early- to mid-Mississippian Little Kalzas succession consists predominantly of calc-alkaline volcanic and volcaniclastic rocks which formed in a continental arc setting. Minor alkali basalt occurs stratigraphically below and above the calc-alkaline rocks. The Little Salmon succession, of mid-Mississippian to early Pennsylvanian age, represents a second cycle of continental arc magmatism. It consists of calc-alkaline andesite and volcaniclastic rocks near Little Salmon Lake, but passes laterally along strike to alkali basalt of within-plate affinity. The occurrence of alkaline magmatism within these continental arc sequences suggests episodic rifting of the arc. The occurrence of Mn-rich exhalite within the rifted arc sequence of the Little Salmon succession suggests that this environment may also have been favourable for production and deposition of metal-rich solutions.

RÉSUMÉ

La cartographie de détail du terrane de Yukon-Tanana dans la région de Glenlyon a permis de reconnaître deux successions volcaniques, et leurs intrusions sous-volcaniques, d'âge Carbonifère. La succession de Little Kalzas, du Mississippien précoce à moyen, est composée de roches volcaniques et volcaniclastiques calco-alcalines qui se sont mises en place dans un environnement d'arc continental. Des basaltes alcalins sont présents à la fois dans les strates sous-jacentes et sus-jacentes aux roches calco-alcalines. La succession de Little Salmon, d'âge Mississippien moyen à Pennsylvanien précoce, représente un second cycle de magmatisme d'arc continental. Elle se compose d'andésites calco-alcalines et de roches volcaniclastiques près du lac Little Salmon, mais elle passe latéralement à des basaltes alcalins d'affinité intra-plaque. La présence de magmatisme alcalin au sein des séquences d'arcs continentaux suggère que l'arc volcanique fût sujet à plusieurs épisodes d'extension. La présence de roches exhalatives enrichie en Mn, au sein des roches volcaniques alcalines de la succession de Little Salmon, suggère que cet environnement pourrait aussi être propice à la production et à l'accumulation de solutions riches en métaux.

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[1] *Contribution to Ancient Pacific Margin NATMAP project*

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INTRODUCTION

Bedrock mapping of Yukon-Tanana Terrane in Glenlyon map area (105L) was initiated in 1998 to evaluate the possible correlation of Yukon-Tanana Terrane southwest of Tintina Fault with that of massive sulphide-hosting strata in the Finlayson Lake district, northeast of the fault, and to assess the potential of the area to host volcanogenic massive sulphide deposits. The Glenlyon area lies along strike to the south of the Finlayson Lake district when ~425 km of dextral displacement is restored along Tintina Fault (Fig. 1).

To date, 1:50 000-scale mapping has focussed on areas of better exposure in Little Kalzas Lake area, in northwest Glenlyon map area (Colpron, 1998), and near Little Salmon Lake, to the south (Colpron and Reinecke, 2000). Detailed mapping in both these areas, augmented by regional reconnaissance and information from limited industry exploration activities, permits a preliminary subdivision of Yukon-Tanana Terrane in Glenlyon map area (Fig. 2). In particular, Carboniferous volcanic successions were identified both in Little Kalzas Lake and Little Salmon Lake areas (Fig. 3; Colpron, 1999a; Colpron and Reinecke, 2000). This paper reviews the stratigraphy of these volcanic successions and presents the results of geochemical analyses of volcanic and subvolcanic rocks (Tables 1-4).

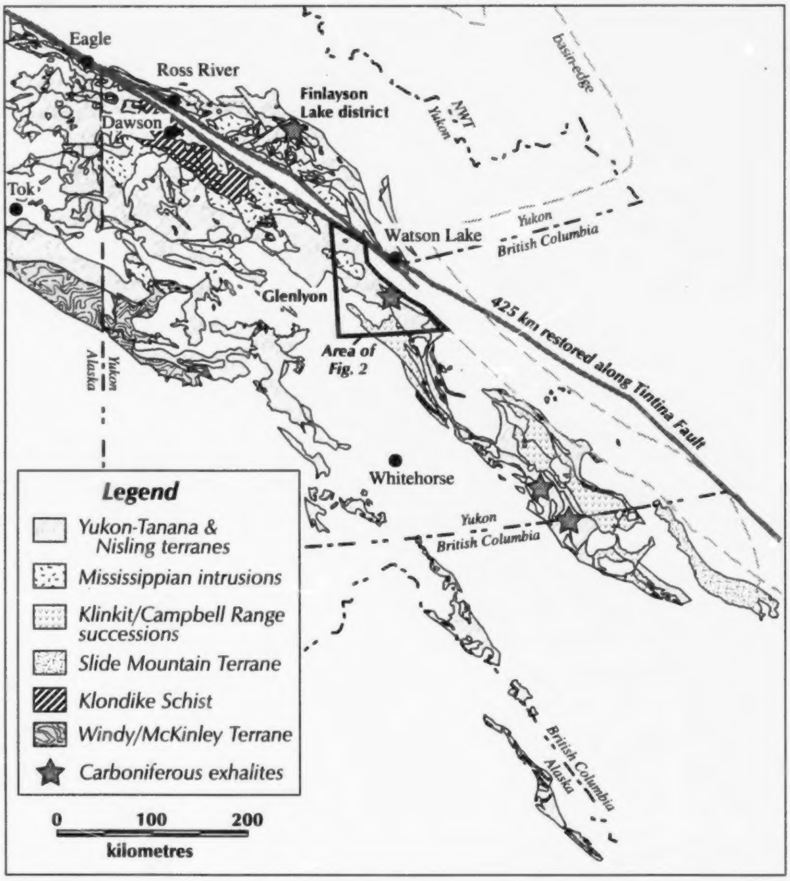

Eagle
Ross River
Dawson
Finlayson Lake district
NWT
Yukon
basin-edge
Tok
Yukon
British Columbia
Watson Lake
Glenlyon
Area of Fig. 2
425 km restored along Tintina Fault
Yukon
Alaska
Whitehorse
Yukon
British Columbia
British Columbia
Alaska
Legend
Yukon-Tanana & Nisling terranes
Mississippian intrusions
Klinkit/Campbell Range successions
Slide Mountain Terrane
Klondike Schist
Windy/McKinley Terrane
Carboniferous exhalites
0
100
200
kilometres

Figure 1. *Distribution of Yukon-Tanana and affiliated terranes (the 'pericratonic' terranes) prior to displacement along Tintina Fault. Location of Glenlyon map area with respect to Finlayson Lake district is shown. Tectonic assemblage map modified after Wheeler and McFeely (1991).*

YUKON-TANANA TERRANE IN GLENLYON MAP AREA

Yukon-Tanana Terrane occupies a 30- to 50-km-wide, northwest-striking belt in the centre of Glenlyon map area (Fig. 2; Campbell, 1967; Tempelman-Kluit, 1979). Ongoing geological mapping and geochronological studies have led to the identification of distinct stratigraphic successions and two Mississippian magmatic suites within the terrane (Fig. 3). In northwest Glenlyon, early to mid-Mississippian volcanic rocks of the Little Kalzas succession conformably overlie quartzite of the Pelmac unit (Fig. 3; Colpron, 1999a). The Pelmac unit rests structurally above amphibolite-grade meta-sedimentary and meta-igneous rocks of uncertain age which are found near Tadru and Ess lakes (Fig. 2; Campbell, 1967; U. Schmidt, pers. comm., 1999). The Pelmac unit and overlying Little Kalzas succession (and subvolcanic intrusions of the Little Kalzas suite) were deformed by south-verging folds and metamorphosed to greenschist facies prior to the intrusion of the Tatlmain batholith at ~340 Ma (Colpron et al., 2000).

To the south, mid-Mississippian to early Pennsylvanian volcanic rocks of the Little Salmon succession unconformably overlie two distinct map units (Fig. 3; Colpron and Reinecke, 2000). To the east, the Little Salmon succession rests above the Drury unit, an arkosic grit and

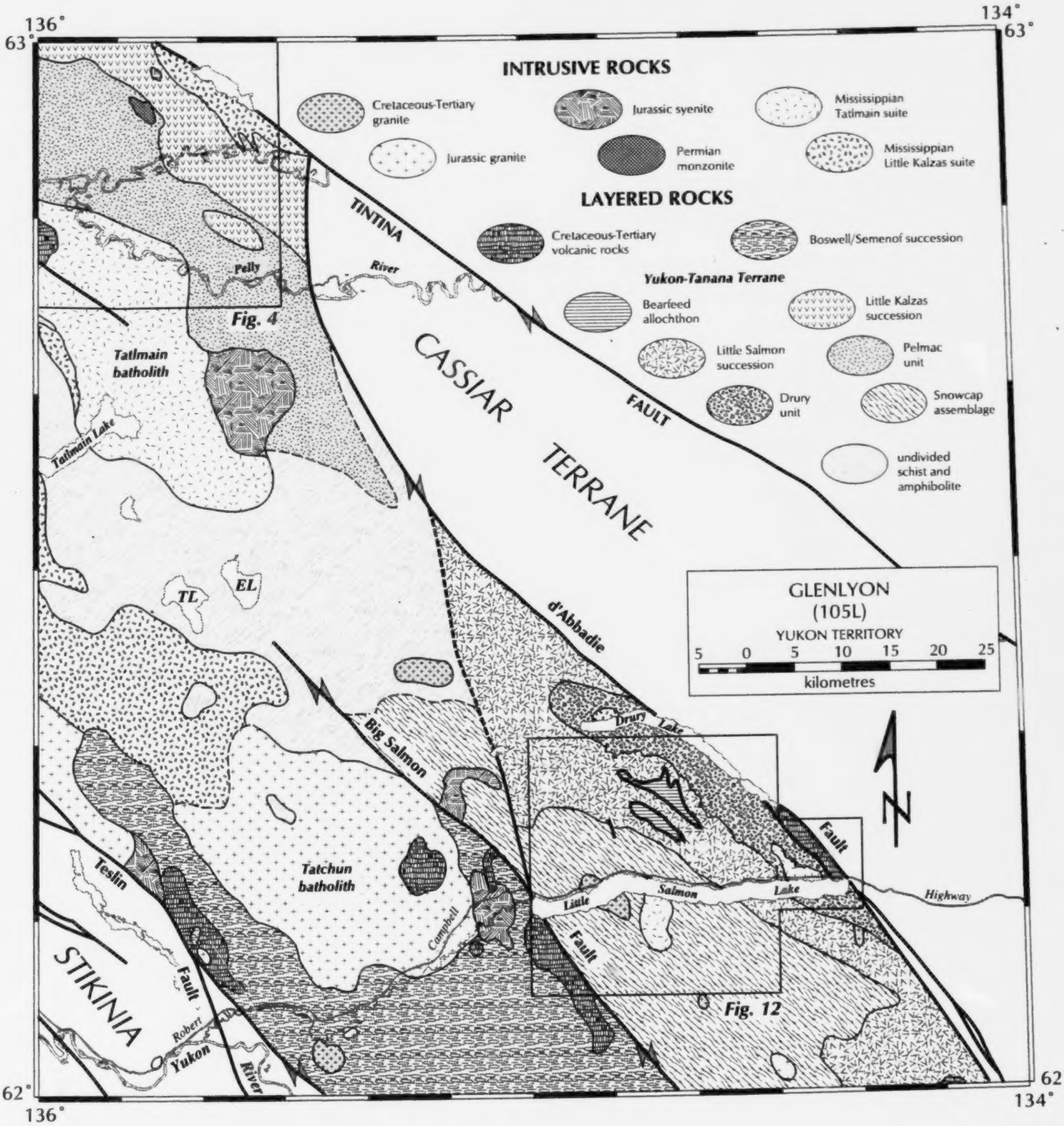

136°
63°
134°
63°
INTRUSIVE ROCKS
Cretaceous-Tertiary granite
Jurassic syenite
Mississippian Tatlmain suite
Jurassic granite
Permian monzonite
Mississippian Little Kalzas suite
LAYERED ROCKS
Cretaceous-Tertiary volcanic rocks
Boswell/Semenof succession
Yukon-Tanana Terrane
Bearfeed allochthon
Little Kalzas succession
Little Salmon succession
Pelmac unit
Drury unit
Snowcap assemblage
undivided schist and amphibolite
TINTINA
FAULT
CASSIAR
TERRANE
Pelly
River
Fig. 4
Tatlmain batholith
Tatlmain Lake
TL
EL
d'Abbadie
Fault
GLENLYON
(105L)
YUKON TERRITORY
5 0 5 10 15 20 25
kilometres
N
Big Salmon
Drury Lake
Tatchun batholith
Campbell
Little Salmon Lake
Highway
Fault
Fig. 12
Teslin
Fault
STIKINIA
Robert
Yukon
River
62°
136°
62°
134°

Figure 2. *Preliminary geological compilation of Glenlyon map area, based on detailed mapping in Little Kalzas Lake (Fig. 4) and Little Salmon Lake (Fig. 12) areas (Colpron, 1998; Colpron, 2000), regional reconnaissance of intervening area, as well as mapping by A.M. Carlos (in Garagan, 1990; southwest of Big Salmon Fault), Campbell (1967) and Gordey and Makepeace (1999). TL = Tadru Lake; EL = Ess Lake.*

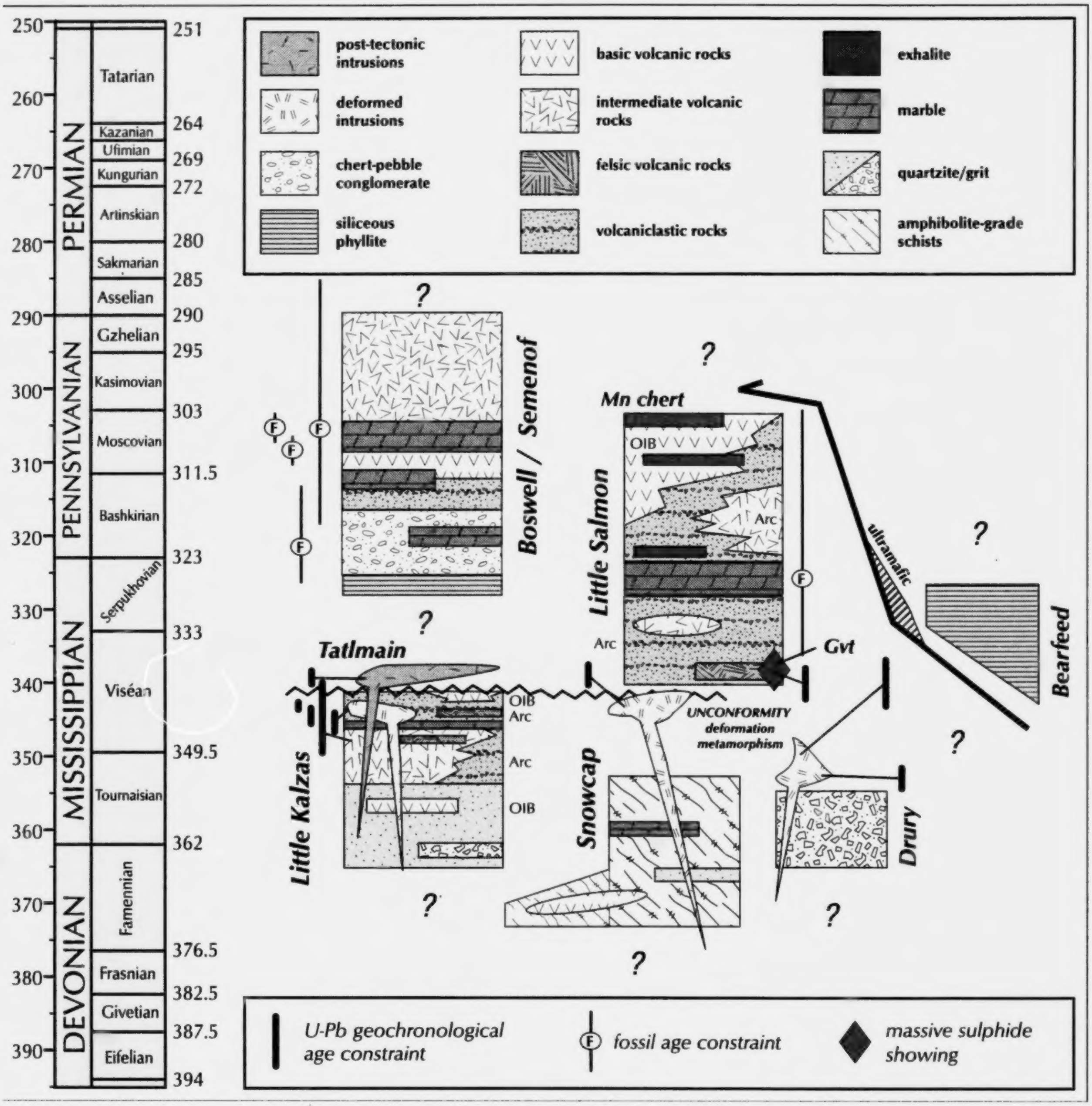

250
260
270
280
290
300
310
320
330
340
350
360
370
380
390
PERMIAN
PENNSYLVANIAN
MISSISSIPPIAN
DEVONIAN
Tatarian
Kazanian
Ufimian
Kungurian
Artinskian
Sakmarian
Asselian
Gzhelian
Kasimovian
Moscovian
Bashkirian
Serpukhovian
Viséan
Tournaisian
Famennian
Frasnian
Givetian
Eifelian
251
264
269
272
280
285
290
295
303
311.5
323
333
349.5
362
376.5
382.5
387.5
394
post-tectonic intrusions
deformed intrusions
chert-pebble conglomerate
siliceous phyllite
basic volcanic rocks
intermediate volcanic rocks
felsic volcanic rocks
volcaniclastic rocks
exhalite
marble
quartzite/grit
amphibolite-grade schists
?
Boswell / Semenof
Mn chert
OIB
Arc
Little Salmon
ultramafic
Bearfeed
Gvt
Tatlmain
OIB
Arc
Arc
OIB
Little Kalzas
UNCONFORMITY
deformation
metamorphism
Snowcap
Drury
U-Pb geochronological age constraint
fossil age constraint
massive sulphide showing

Figure 3. *Composite stratigraphic columns for subdivisions of Yukon-Tanana Terrane in Glenlyon map area. Geochemical affinities for volcanic rocks of the Little Kalzas and Little Salmon successions are shown (explanations are given in the text). Stratigraphy of Boswell/Semenof succession (compiled from Tempelman-Kluit in Gordey et al., 1991) is shown for comparison with Pennsylvanian section in Finlayson Lake district (see Murphy, this volume). OIB = ocean island basalt.*

quartzite unit which is intruded by early Mississippian granodiorite. To the west, the volcanic rocks overlie a mixture of meta-sedimentary and meta-igneous rocks which record a poly-metamorphic history – the Snowcap assemblage (Colpron, 2000). These rocks are intruded by diorite plutons of the Tatlmain suite (ca. 340 Ma) which are likely subvolcanic to the Little Salmon succession. Accordingly, the Snowcap assemblage forms the basement onto which volcanic rocks of the Little Salmon succession were erupted. The relationship between the Snowcap assemblage and similar metamorphic rocks in the vicinity of Tadru and Ess lakes is unknown. They may be part of the same lithotectonic assemblage.

The Boswell/Semenof succession (Boswell and Semenof formations of Tempelman-Kluit, 1984) is juxtaposed to the Snowcap assemblage along Big Salmon Fault (Fig. 2). It consists of dark grey slate, greywacke and chert-pebble conglomerate, limestone, volcaniclastic rocks and andesitic greenstone of Pennsylvanian age (Fig. 3; Tempelman-Kluit *in:* Gordey et al., 1991; Poulton et al., 1999). Although it is not currently considered part of Yukon-Tanana Terrane (Wheeler et al., 1991 included it in Slide Mountain Terrane; Gordey and Makepeace, 1999 in Quesnel Terrane), the resemblance of Boswell/Semenof succession to recently identified Pennsylvanian strata in Yukon-Tanana Terrane of Finlayson Lake district (Murphy, this volume) requires a re-evaluation of its tectonic setting. Dark grey siliceous phyllite of the Bearfeed allochthon, which sits in klippen overlying the Little Salmon succession (Fig. 2; Colpron, 2000; Colpron and Reinecke, 2000), is possibly correlative with the base of the Boswell/Semenof succession.

Although volcanic rocks of the Little Kalzas and Little Salmon successions are pervasively deformed and generally metamorphosed to greenschist facies (chlorite to biotite grade), the exceptional preservation of primary textures in these rocks warrants the use of protolith nomenclature for their description. It must also be noted that the interpretations of the geochemical data presented in this paper (Tables 1-4) are primarily based on elements which are considered immobile during low-grade metamorphic reactions (e.g. Rollinson, 1993).

LITTLE KALZAS SUCCESSION

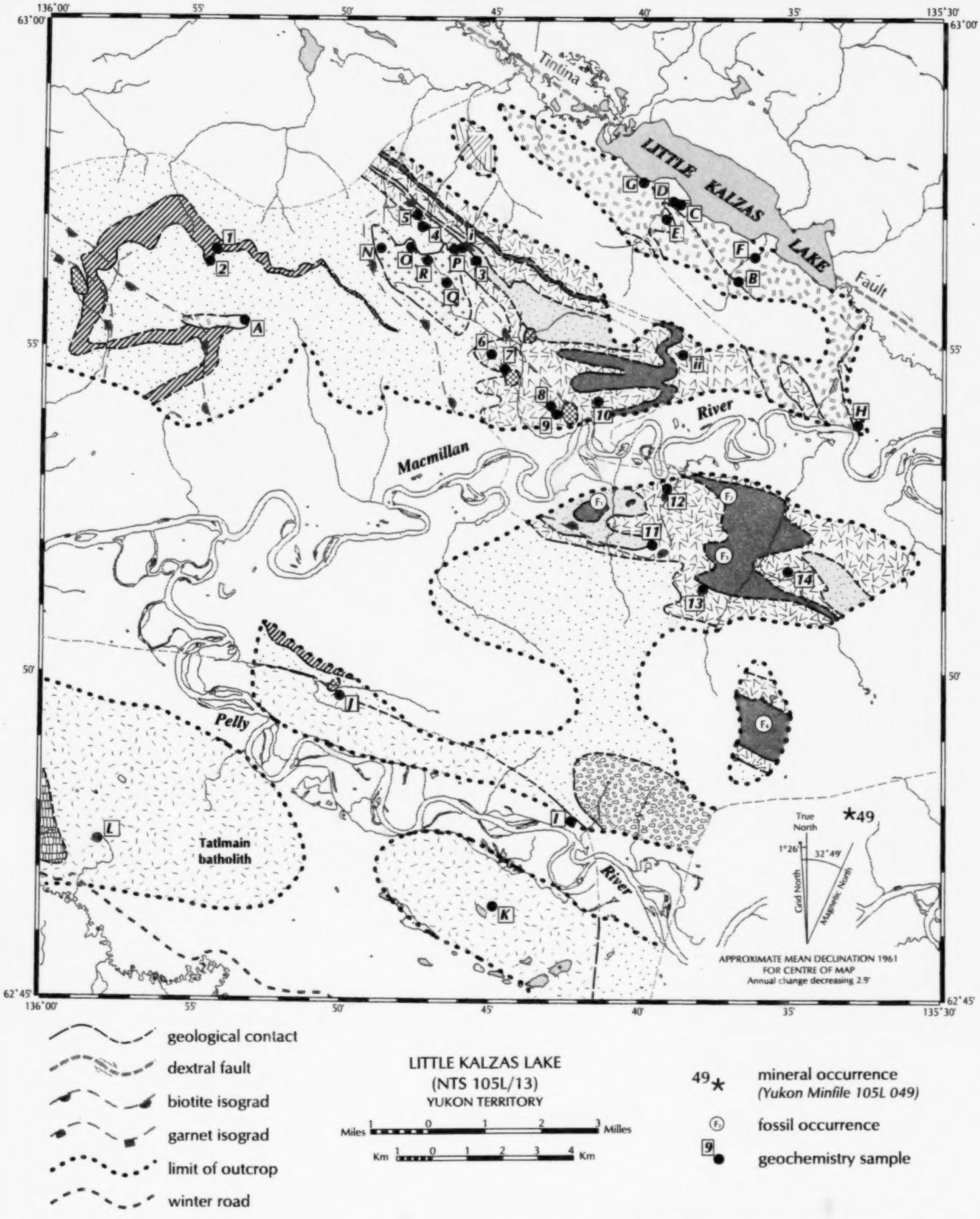
Volcanic rocks of the Little Kalzas succession occupy a northwest-trending belt in the northeast half of Little Kalzas Lake map area (Fig. 4). The volcanic rocks are subdivided by a marble horizon into a lower and an upper unit (units 2-4 of Colpron, 1999a). Below the marble, the volcanic succession consists predominantly of massive, plagioclase-phyric andesite (Fig. 5) and minor rhyolite. The andesite passes both upward and laterally to the southeast into a sequence of volcaniclastic rocks which is dominated by light green epiclastic sandstone and argillite. South of Macmillan River, epiclastic and tuffaceous rocks comprise the bulk of the lower unit. Outcrops of massive andesite occur sporadically within the volcaniclastic rocks.

Above the marble, the Little Kalzas succession consists of a mixture of sedimentary and volcanic rocks (Colpron, 1999a). Carbonaceous phyllite and quartzite are dominant north of Macmillan River. Plagioclase-phyric andesite occurs only locally north of Macmillan River, and a rhyolitic tuff is exposed on the south-facing slope above the river. South of the river, light green epiclastic argillite, sandstone and grit make up the bulk of the upper unit. The sequence is capped by a dolomitic quartzite. Massive basalt outcrops are restricted to a small creek to the southwest of the dolomitic quartzite exposures.

Volcanic rocks also occur within orthoquartzite of the Pelmac unit (Fig. 4). They consist predominantly of light green volcaniclastic sandstone and arkosic grit. Mafic volcanic (flow?) rocks are restricted to a few exposures within the volcaniclastic unit.

Mafic volcanic rocks from both the Pelmac unit and the upper part of Little Kalzas succession plot in the alkaline basalt field on discriminant diagrams (Figs. 6 a,b). They have trace element characteristics of within-plate alkali basalts: they plot in the ocean island basalt (OIB) field on the Th-Zr-Nb diagram (Fig. 6c); they are enriched in TiO_2, P_2O_5, and incompatible elements; and they exhibit a slight positive Nb anomaly relative to Th and La on primitive mantle-normalized plots (Fig. 7b). Basalts of the Pelmac unit have higher Ti/V ratios (Fig. 6b) and have slightly more enriched trace element contents (Fig. 7b) than those of the upper part of the Little Kalzas succession, indicating a higher degree of alkalinity. The geochemical character of these volcanic rocks is typical of a rift environment (e.g. Goodfellow et al., 1995).

Andesites from the Little Kalzas succession plot in the compositional range of basaltic andesites on the trace element-based classification diagram (Fig. 6a). They occupy the calc-alkaline basalt field on the Th-Zr-Nb diagram (Fig. 6c) and exhibit a pronounced negative Nb anomaly and a slight negative Ti anomaly on primitive mantle-normalized multi-element plots (Fig. 7a). Felsic rocks of the Little Kalzas succession are rhyolitic in


136°00'
55'
50'
45'
40'
35'
135°30'
63°00'
Tintina
Fault
LITTLE KALZAS LAKE
Macmillan
River
Pelly
River
Tatlmain batholith
1
2
3
4
5
6
7
8
9
10
11
12
13
14
i
ii
A
B
C
D
E
F
G
H
I
J
K
L
N
O
P
Q
R
F1
F2
F3
F4
True North
Grid North
Magnetic North
1°26'
32°49'
★49
APPROXIMATE MEAN DECLINATION 1961 FOR CENTRE OF MAP
Annual change decreasing 2.9'
62°45'
geological contact
dextral fault
biotite isograd
garnet isograd
limit of outcrop
winter road
LITTLE KALZAS LAKE
(NTS 105L/13)
YUKON TERRITORY
Miles 1 0 1 2 3 Miles
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49★ mineral occurrence (Yukon Minfile 105L 049)
F fossil occurrence
9● geochemistry sample

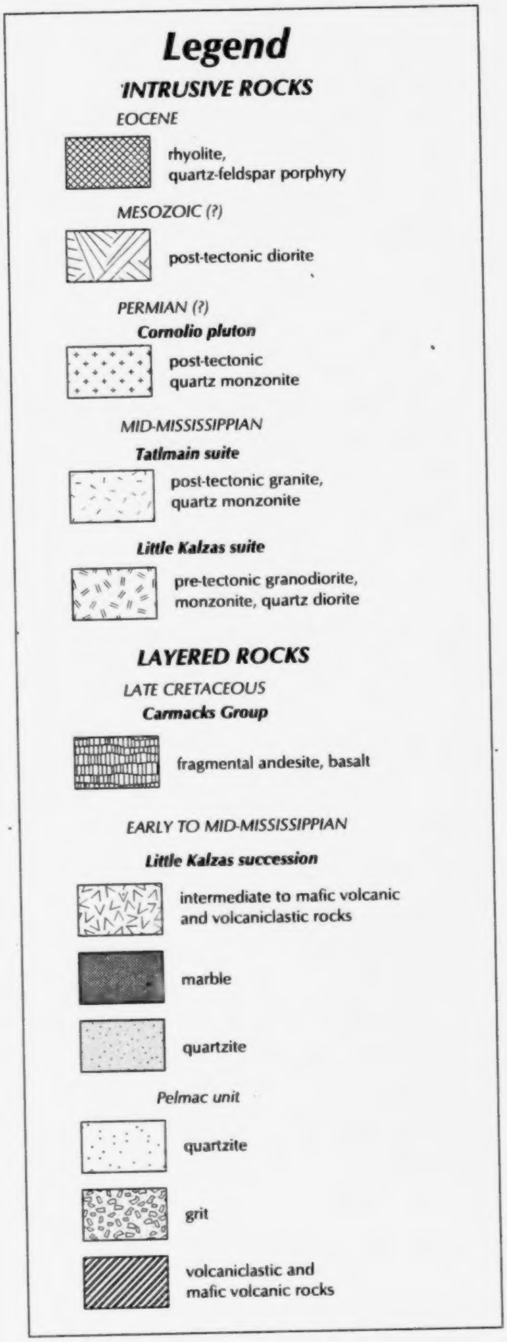

Legend
INTRUSIVE ROCKS
EOCENE
rhyolite, quartz-feldspar porphyry
MESOZOIC (?)
post-tectonic diorite
PERMIAN (?)
Cornolio pluton
post-tectonic quartz monzonite
MID-MISSISSIPPIAN
Tatlmain suite
post-tectonic granite, quartz monzonite
Little Kalzas suite
pre-tectonic granodiorite, monzonite, quartz diorite
LAYERED ROCKS
LATE CRETACEOUS
Carmacks Group
fragmental andesite, basalt
EARLY TO MID-MISSISSIPPIAN
Little Kalzas succession
intermediate to mafic volcanic and volcaniclastic rocks
marble
quartzite
Pelmac unit
quartzite
grit
volcaniclastic and mafic volcanic rocks

Figure 4. *Geological map of Little Kalzas Lake area. Modified after Colpron (1998). Arabic numerals refer to geochemical analyses listed in Table 1; roman numerals to those in Table 3; capital letters to analyses presented in Table 4.*

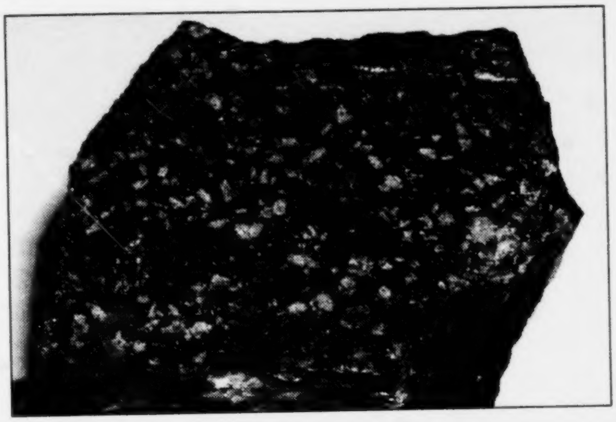


Figure 5. *Plagioclase-phyric andesite, Little Kalzas succession. Hand specimen is approximately 5 cm across.*

composition (Fig. 6a) and plot in the volcanic arc field on the Ta-Yb diagram (Fig. 6d). Their trace element pattern exhibit negative anomalies in Nb and Ti typical of the calc-alkaline magma series. High Th/Yb ratios for the andesites (Fig. 8) and the ubiquitous Proterozoic inheritance in zircons from comagmatic felsic rocks (J.K. Mortensen, pers. comm., 1999) suggest contamination from (or melting of) a crustal source. Together, these geochemical charateristics suggest a continental arc setting for the Little Kalzas succession.

LITTLE KALZAS INTRUSIVE SUITE

Granitoid rocks of the Little Kalzas intrusive suite are broadly coeval with volcanic rocks of the Little Kalzas succession (343-346 Ma; Colpron et al., 2000) and are likely their subvolcanic equivalent. They form a large intrusive complex southwest of Little Kalzas Lake and occur as a small pluton intruding quartzite and volcaniclastic rocks of the Pelmac unit in the northeastern part of the map area (Fig. 4). The dominant phase of the Little Kalzas suite consists of a fine- to medium-grained biotite (± hornblende) diorite, which is intruded by a tonalitic phase (Figs. 9, 10a). These rocks are strongly foliated and contain abundant xenoliths of country rocks. Both dioritic and tonalitic phases of the Little Kalzas suite have peraluminous compositions (Fig. 10b). Along Macmillan River, the Little Kalzas suite is represented by a metaluminous potassium-feldspar megacrystic granite (Fig. 10 a,b). The Little Kalzas suite occupies the volcanic arc field on discriminant diagrams (Fig. 10 c,d) and exhibits trace element patterns typical of arc granites (Fig. 11a). The rare earth element patterns illustrate the differentiated nature of the Little Kalzas suite (Fig. 11b).

LITTLE SALMON SUCCESSION

The Little Salmon succession is exposed in a 4- to 8-km-wide belt which extends northwesterly from the eastern part of Little Salmon Lake (Fig. 12). It occupies a broad synclinorium and rests with apparent unconformity on arkosic grit and quartzite of the Drury unit to the northeast, and on metamorphic rocks of the Snowcap assemblage to the southwest (Fig. 3; Colpron and Reinecke, 2000). The Little Salmon succession is structurally overlain by an allochthonous sheet of dark grey siliceous phyllite with subordinate graded sandstone, conglomerate and marble (Bearfeed allochthon; Fig. 12). Rocks of the Bearfeed allochthon may correlate with the basal part of Boswell/Semenof succession (Tempelman-Kluit *in:* Gordey et al., 1991).

The Little Salmon succession is dominated by volcaniclastic rocks (both epiclastic and tuffaceous, Colpron and Reinecke, 2000). A prominent marble unit of late Mississippian - early Pennsylvanian age (E.W. Bamber *in:* Colpron and Reinecke, 2000) occurs in the lower part of the Little Salmon succession (Figs. 3, 12). Dacite and quartz-feldspar porphyry mark the base of the sequence

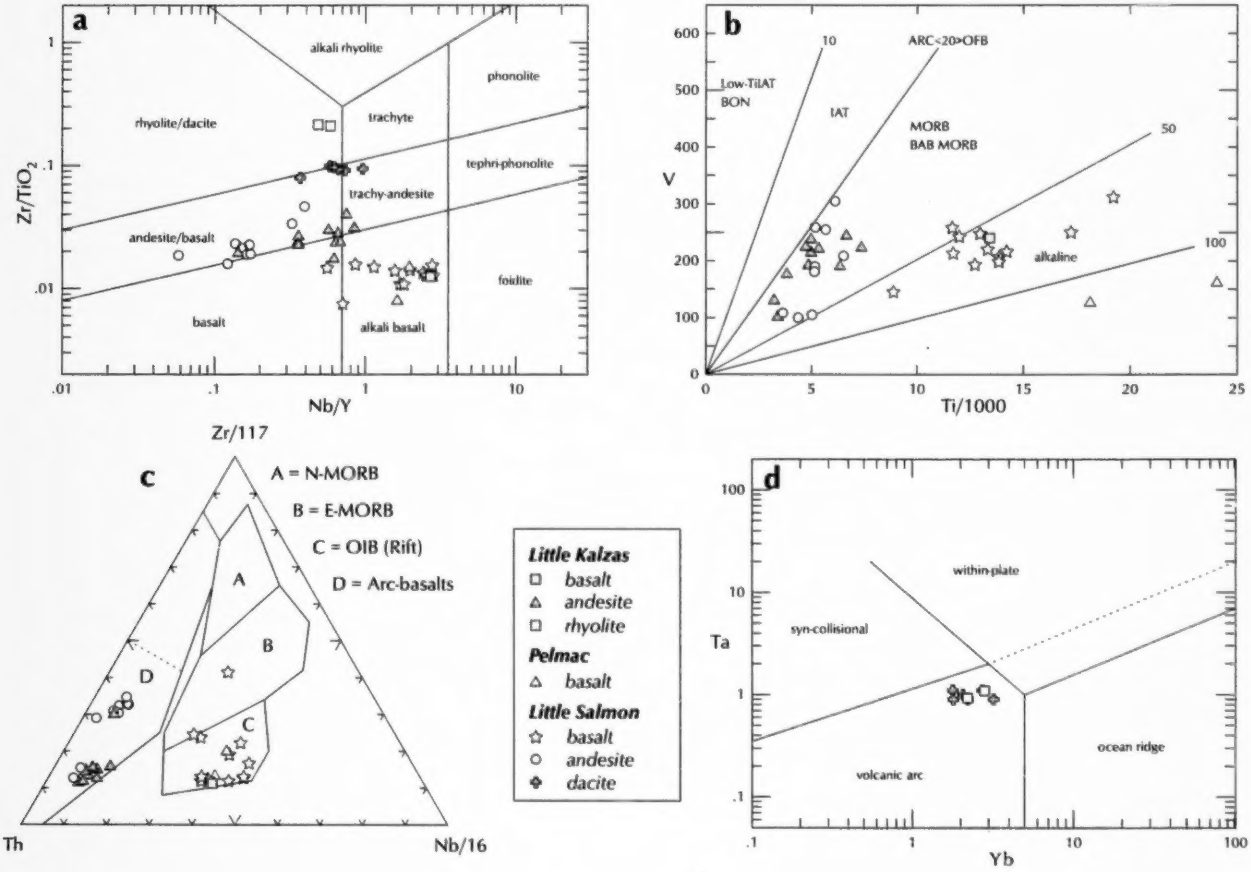


Figure 6. *Discriminant diagrams for volcanic rocks of Yukon-Tanana Terrane in Glenlyon map area. (a) Zr/Ti-Nb/Y diagram of Winchester and Floyd (1977) as modified by Pearce (1996). (b) Ti-V diagram of Shervais (1982). IAT = island arc tholeiite; BON = boninite; OFB = ocean-floor basalt; MORB = mid-ocean ridge basalt; BAB = back-arc basin. (c) Th-Zr-Nb diagram of Wood (1980). MORB = mid-ocean ridge basalt; N-MORB = normal MORB; E-MORB = enriched MORB; OIB = ocean island basalt. (d) Ta-Yb diagram of Pearce et al. (1984) for felsic volcanic rocks of the Glenlyon area. Analytical data are presented in Tables 1-3.*

near Little Salmon Lake, along the western flank of the synclinorium (Fig. 12). A small sulphide occurrence is present at the base of the felsic volcanic unit (Colpron, 1999b). Zircons from the quartz-feldspar porphyry yielded a U-Pb age of ca. 340 Ma (Colpron et al., 2000).

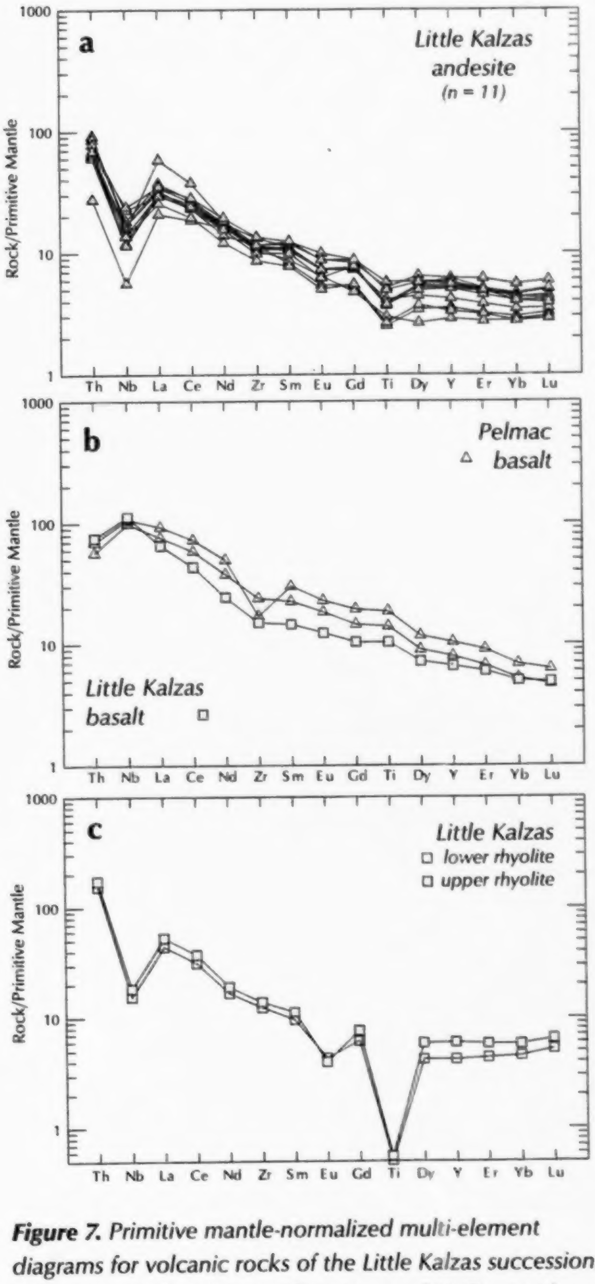


Figure 7. Primitive mantle-normalized multi-element diagrams for volcanic rocks of the Little Kalzas succession. Primitive mantle values are from Sun and McDonough (1989). Analytical data are presented in Tables 1 and 3.

Volcanic rocks of intermediate composition (with subordinate mafic and felsic phases) form prominent exposures on the south-facing slopes overlooking Little Salmon Lake (Fig. 12). These rocks are generally massive; pillow structures were observed at only one locality. Intermediate volcanic rocks grade laterally into tuffaceous rocks and epiclastic phyllite and sandstone. Along strike to the northwest, they occur as isolated lenses within the volcaniclastic rocks.

A distinctive plagioclase-phyric volcanic unit of intermediate composition is ubiquitous above the marble in the northwestern exposures of the Little Salmon

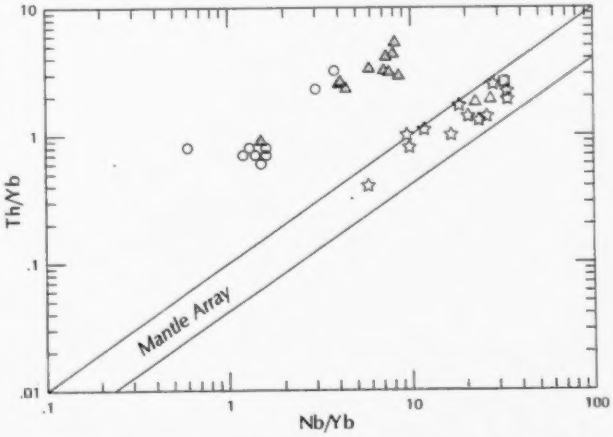


Figure 8. Th/Yb vs. Nb/Yb diagram for intermediate and mafic volcanic rocks of Yukon-Tanana Terrane in Glenlyon map area. Legend for symbols is shown in Figure 6. Enrichment in Th/Yb ratio (relative to mantle array) indicates either crustal contamination or subducted slab metasomatism.

Figure 9. Tonalite dyke intruding diorite, Little Kalzas intrusive suite.

succession (Figs. 12, 13a). It contains up to 40-50% coarse (up to 3 cm), subhedral to euhedral plagioclase crystals in a fine-grained chloritic matrix. The abundance and large size of the plagioclase crystals suggest that these rocks may represent high-level subvolcanic intrusions. However, fine intercalations of dolostone and epiclastic sandstone with the crystal-rich volcanic rocks indicate that at least part of this unit has an extrusive origin.

In the northwestern part of the map area (Fig. 12), the Little Salmon succession comprises a higher proportion of mafic flows and agglomerates. Plagioclase- and hornblende-phyric basalts are dominant lithologies. The basalts commonly display well-preserved pillow structures (Fig. 13b). Fragmental units, including pillow breccias and mass-flow deposits (poorly sorted, polymictic breccia with sericitic and/or hematitic matrix), are common adjacent to basaltic flow units. The basalts are intercalated with lapilli tuffs and reworked volcaniclastic rocks.

Two cherty horizons occur in the upper part of the Little Salmon succession in the nortwestern part of the map area (Fig. 14). These siliceous rocks can be traced for up to 4 km along strike (Colpron, 2000). They were originally mapped as rhyolite on account of their very fine grain size and massive appearance (Colpron, 2000). However, their high silica (80-95% SiO_2), low potassium (<0.25% K_2O), and low zirconium (<50 ppm Zr) contents do reflect a rhyolitic composition (Colpron, unpublished data). The lower horizon is light grey to light green and commonly contains brown-weathering dolomitic pods. Adjacent

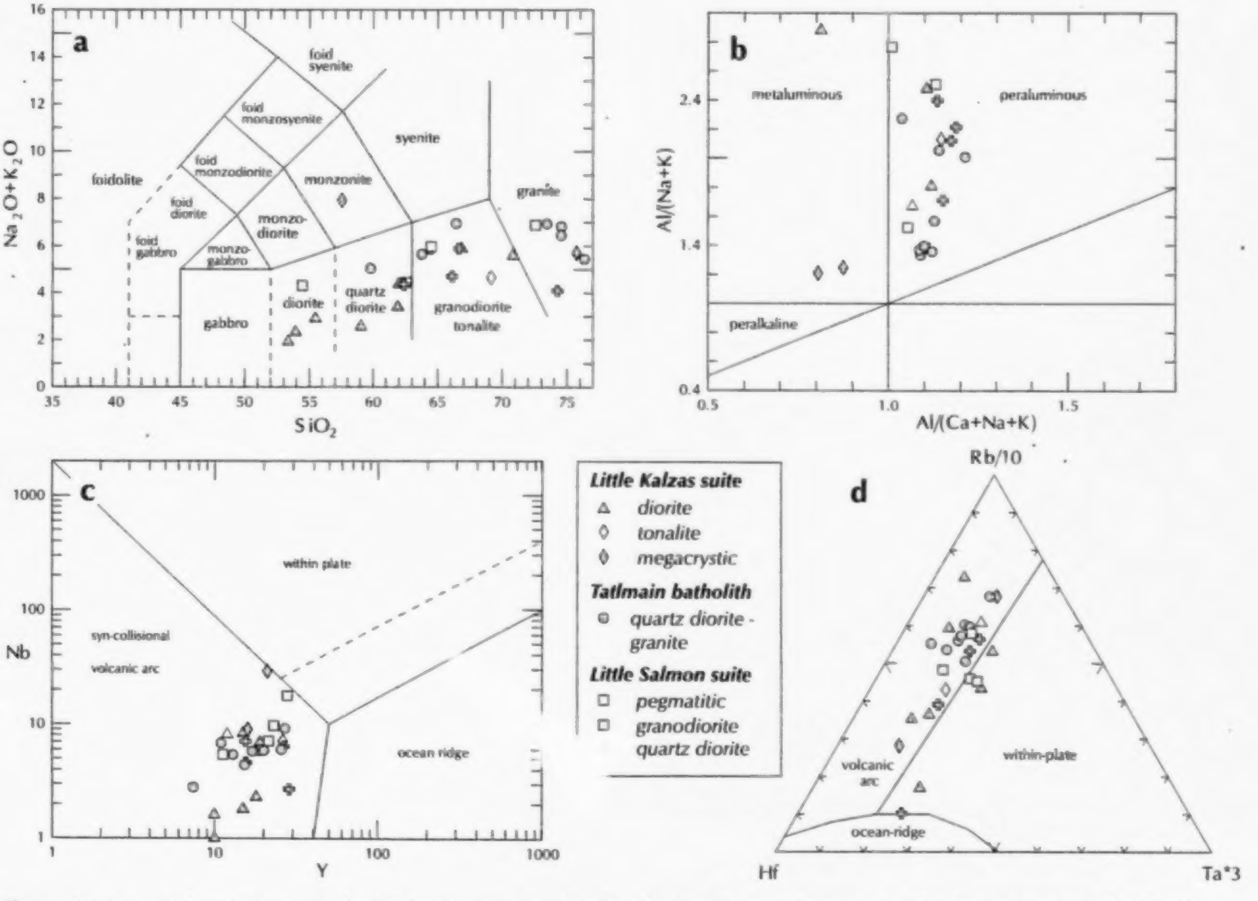


Figure 10. Discriminant diagrams for Mississippian granitoids of Yukon-Tanana Terrane in Glenlyon map area. (a) Total alkalis – silica diagram of LeBas et al. (1986) adapted for plutonic rocks using the nomenclature of Le Maitre et al. (1989). (b) Shand's index diagram of Maniar and Piccoli (1989). (c) Nb-Y diagram of Pearce et al. (1984). (d) Hf-Rb-Ta diagram of Harris et al. (1986). Analytical data are listed in Table 4.

basalt exposures also contain dolomitic pods. The upper siliceous horizon is light grey, purple and pink in colour and is gradationally overlain by a 50-cm-thick red piemontite (Mn-rich epidote) chert horizon. This horizon is interpreted as an exhalative unit. It is restricted to a single locality in the map area (Fig. 12).

Intermediate rocks of the Little Salmon succession are andesitic in composition (Fig. 6a). They plot in the calc-alkaline arc field on the Th-Zr-Nb diagram (Fig. 6c). The felsic rocks have dacitic to trachy-andesitic compositions (Fig. 6a) and plot in the volcanic arc field on a Ta-Yb diagram (Fig. 6d). Both andesites and dacites have trace

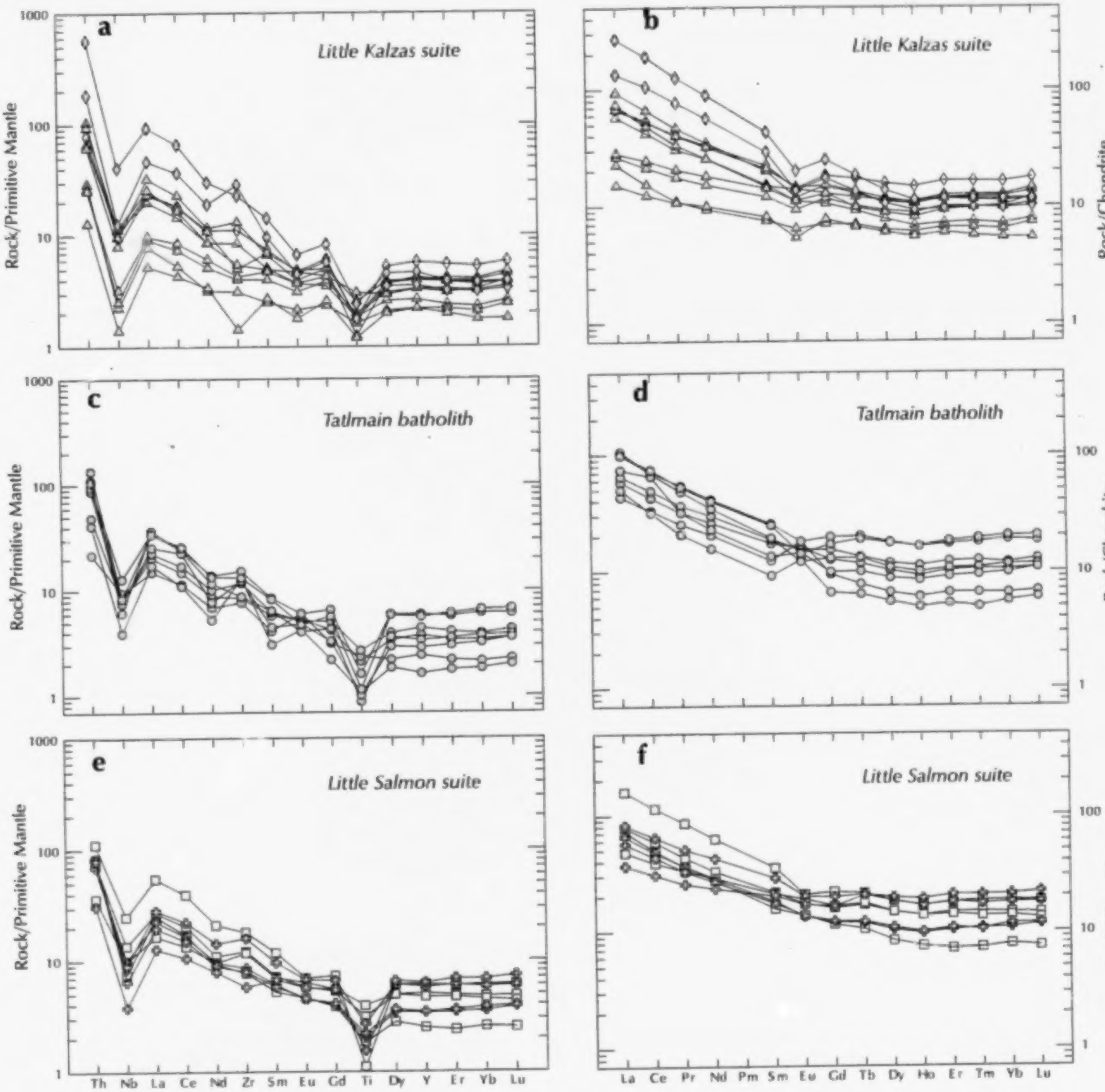
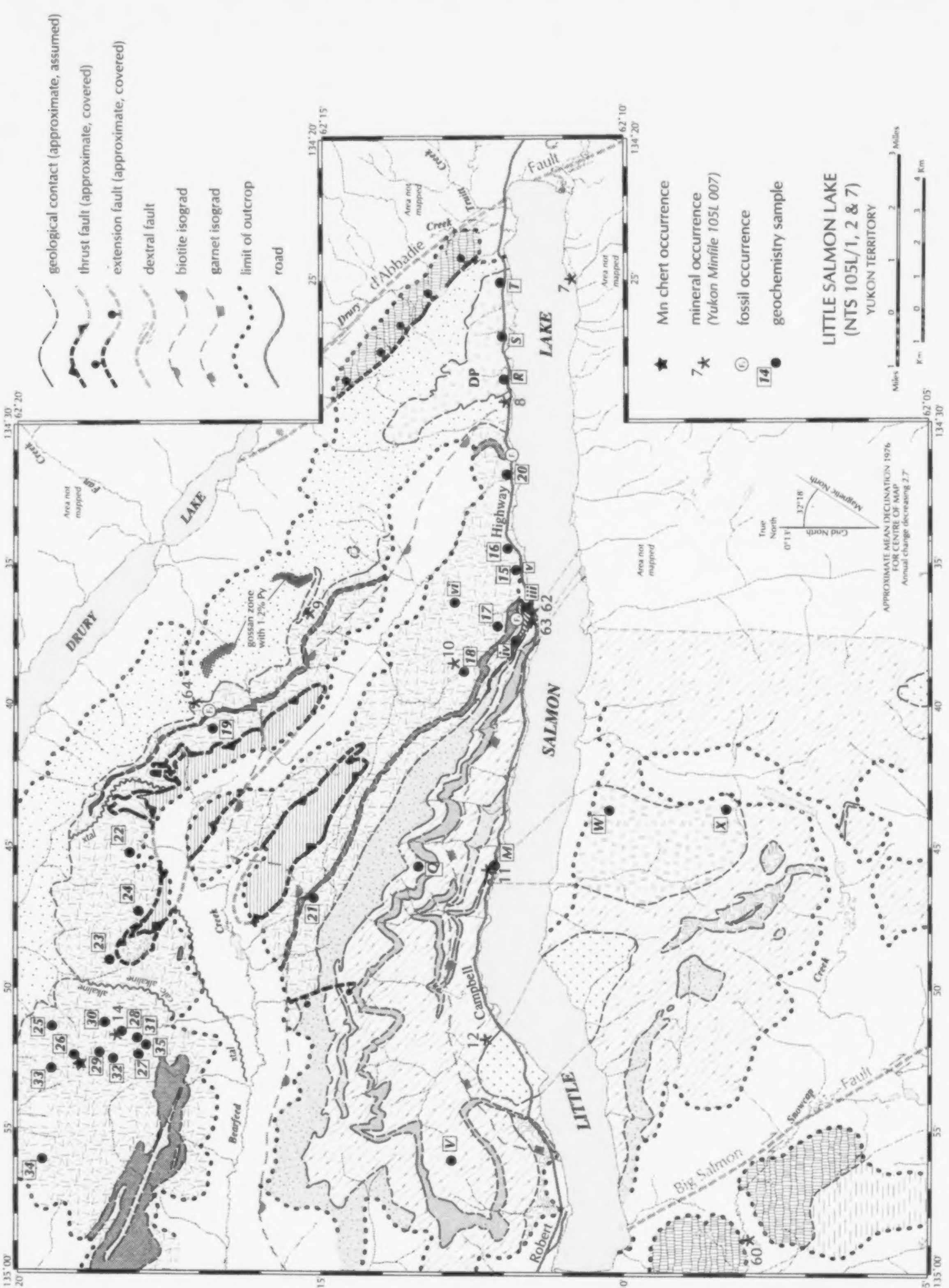


Figure 11. Primitive mantle-normalized multi-element diagrams (a,c,e) and chondrite-normalized rare earth element patterns (b,d,f) for Mississippian granitoids of Yukon-Tanana Terrane in Glenlyon map area. Primitive mantle values are from Sun and McDonough (1989). Chondrite values are from McDonough and Sun (1995). Analitical data is given in Table 4. Legend for symbols is shown in Figure 10.


geological contact (approximate, assumed)
thrust fault (approximate, covered)
extension fault (approximate, covered)
dextral fault
biotite isograd
garnet isograd
limit of outcrop
road
Mn chert occurrence
mineral occurrence (Yukon Minfile 105L 007)
fossil occurrence
geochemistry sample
LITTLE SALMON LAKE (NTS 105L/1, 2 & 7)
YUKON TERRITORY
Miles
Km
DRURY LAKE
Drury Creek
d'Abbadie Creek
Truitt Creek
Fault
Area not mapped
LITTLE SALMON LAKE
Highway
Campbell
Robert
Big Salmon
Snowcap Creek
Fault
Bearfeed
Creek
gossan zone with 1-2% Py
alkaline
xtal
DP
True North
Grid North
Magnetic North
APPROXIMATE MEAN DECLINATION 1976 FOR CENTRE OF MAP
Annual change decreasing 2.7'
135°00'
134°30'
134°20'
62°20'
62°15'
62°10'
62°05'

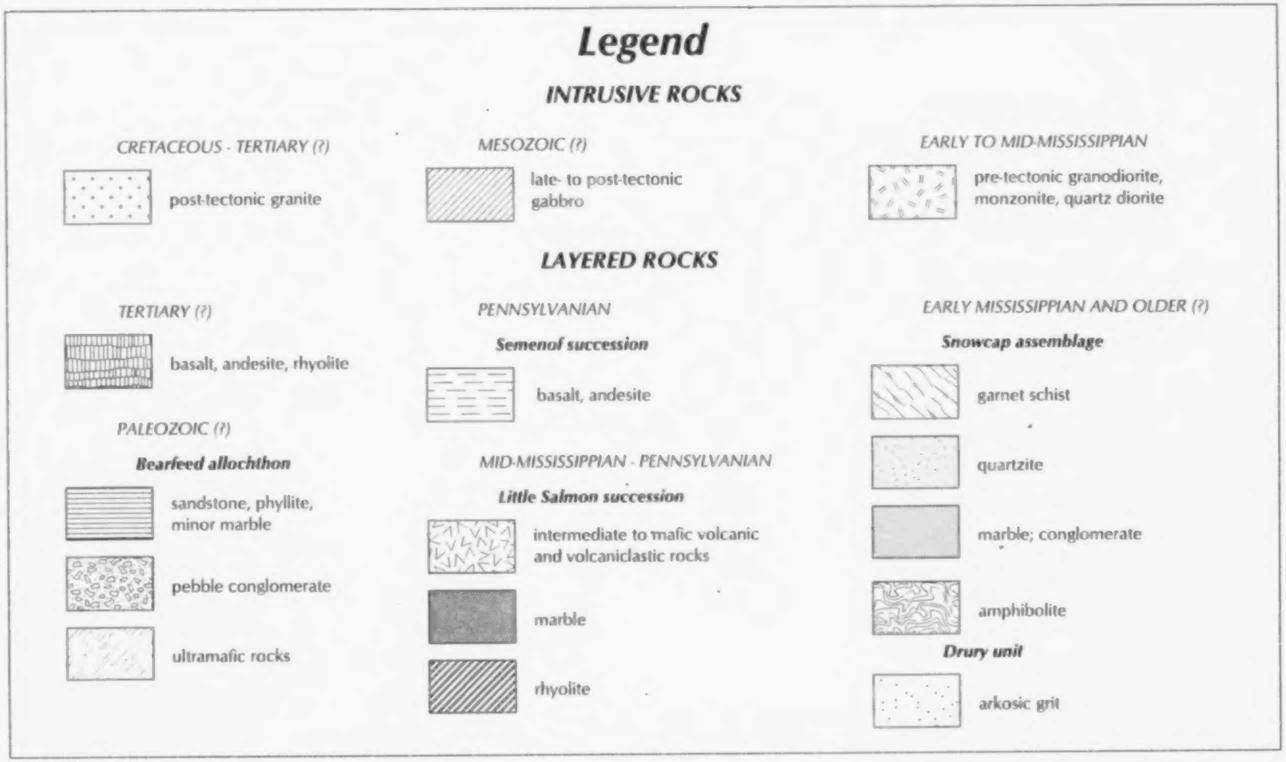

Legend
INTRUSIVE ROCKS
CRETACEOUS - TERTIARY (?)
post-tectonic granite
MESOZOIC (?)
late- to post-tectonic gabbro
EARLY TO MID-MISSISSIPPIAN
pre-tectonic granodiorite, monzonite, quartz diorite
LAYERED ROCKS
TERTIARY (?)
basalt, andesite, rhyolite
PALEOZOIC (?)
Bearfeed allochthon
sandstone, phyllite, minor marble
pebble conglomerate
ultramafic rocks
PENNSYLVANIAN
Semenof succession
basalt, andesite
MID-MISSISSIPPIAN - PENNSYLVANIAN
Little Salmon succession
intermediate to mafic volcanic and volcaniclastic rocks
marble
rhyolite
EARLY MISSISSIPPIAN AND OLDER (?)
Snowcap assemblage
garnet schist
quartzite
marble; conglomerate
amphibolite
Drury unit
arkosic grit

Figure 12 (left). *Geological map of Little Salmon Lake area (Colpron, 2000). Wavy line labelled 'xtal' indicates the southern extent of crystal-rich (plagiocalse-phyric) volcanic rocks. Wavy line labelled 'alkaline/calc-alkaline' indicates approximate location of transition between calc-alkaline (to the southwest) and alkaline compositions (to the northwest). Arabic numerals refer to geochemical analyses presented in Table 2; roman numerals to those in Table 3; capital letters to analyses shown in Table 4. DP = Drury pluton.*

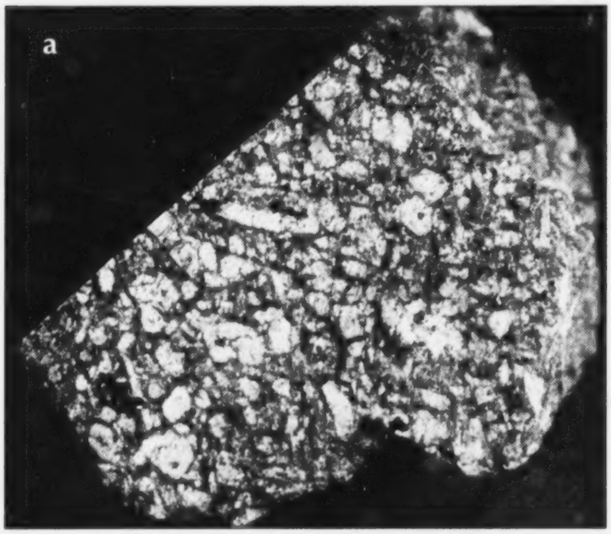


Figure 13. *(a) Plagioclase-phyric volcanic unit, Little Salmon succession. Hand specimen is approximately 9 cm across. (b) Pillow basalt, Little Salmon succession.*

element patterns characteristic of calc-alkaline magmas (Figs. 15 a,c). The dacite displays a distinctive positive Zr anomaly relative to Nd and Sm on primitive mantle-normalized multi-element plots (Fig. 15c). Proterozoic inheritance in zircons from the felsic rocks (J.K. Mortensen, pers. comm., 1999) and elevated Th/Yb ratios in the andesites (Fig. 8) indicate interaction of the magma with continental crust. These rocks probably formed in a continental arc setting.

The mafic rocks are basalts of subalkaline to alkaline affinities (Fig. 6 a,b). They plot in the ocean island basalt (OIB) field of the Th-Zr-Nb diagram (Fig. 6c) and have trace element patterns typical of alkali basalts (Fig. 15b). These geochemical characteristics are typical of rift environments (e.g. Goodfellow et al., 1995).

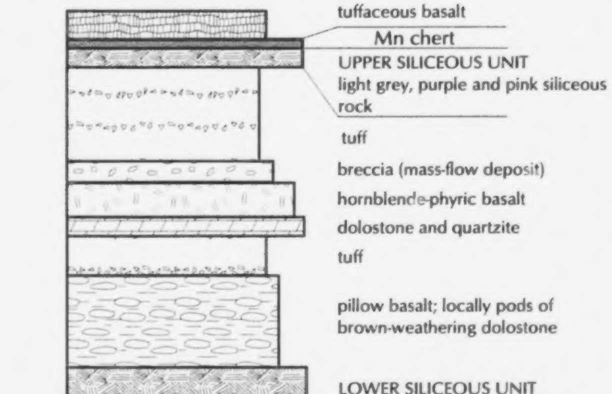

tuffaceous basalt
Mn chert
UPPER SILICEOUS UNIT
light grey, purple and pink siliceous rock
tuff
breccia (mass-flow deposit)
hornblende-phyric basalt
dolostone and quartzite
tuff
pillow basalt; locally pods of brown-weathering dolostone
LOWER SILICEOUS UNIT
light grey to light green very fine-grained siliceous rock; locally contains brown-weathering dolomitic pods
dark grey argillite
light green tuff
crystal-rich basalt; hornblende-phyric basalt
50
metres
0

Figure 14. *Stratigraphy of the upper part of Little Salmon succession in northwestern Little Salmon Lake map area.*

TATLMAIN BATHOLITH AND LITTLE SALMON SUITE

The post-tectonic Tatlmain batholith intrudes deformed early Mississippian strata of Yukon-Tanana Terrane in northwest Glenlyon (Fig. 2). A Late Triassic – Early Jurassic age was assigned to the Tatlmain batholith based on biotite K-Ar cooling dates in Carmacks map area (Fig. 16; Stevens et al., 1982; Tempelman-Kluit, 1984). Preliminary U-Pb zircon age data indicate a mid-Mississippian age (ca. 340 Ma; Colpron et al., 2000). Tatlmain batholith is an undeformed, homogeneous, coarse-grained biotite (± hornblende) quartz diorite to granite over its entire area (Figs. 10a, 16). The only compositional variation observed in Tatlmain batholith is in the amount of mafic minerals present; biotite, and less commonly hornblende, represent 5-15% of the rock. Tatlmain batholith imposes a metamorphic aureole on quartzite and calc-silicate rocks of the Pelmac unit south of Pelly River. Near Diamain Lake, the coarse-grained granite contains xenoliths of foliated, fine-grained granodiorite similar to the main phase of the 343-346 Ma Little Kalzas suite (Figs. 16, 17).

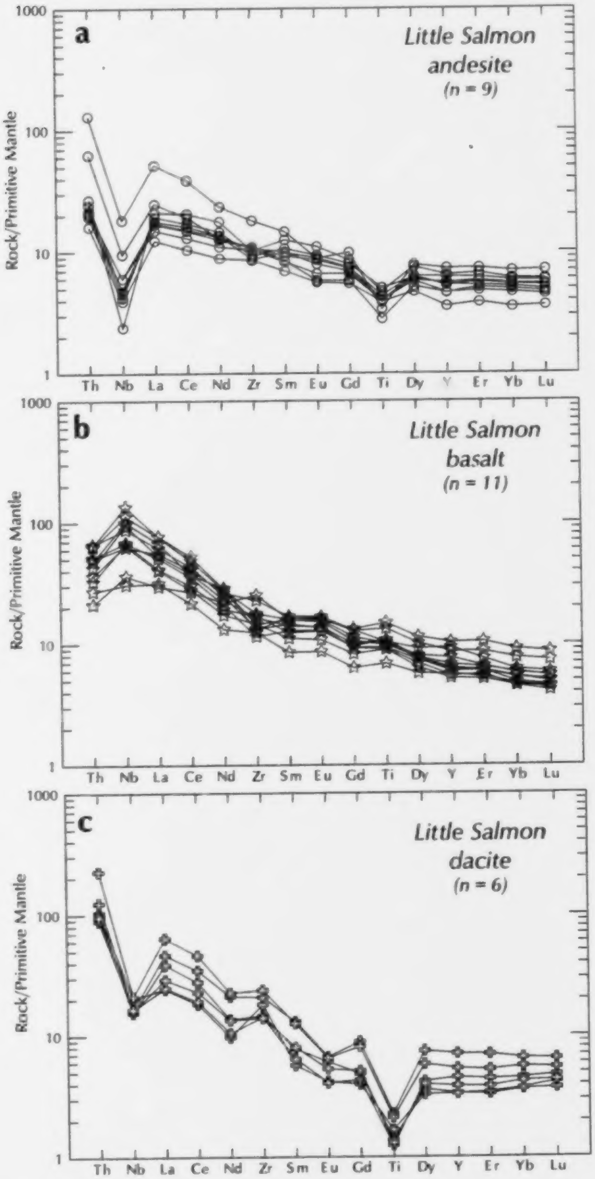


Figure 15. Primitive mantle-normalized multi-element diagrams for volcanic rocks of the Little Salmon succession. Primitive mantle values are from Sun and McDonough (1989). Analytical data are presented in Tables 2 and 3.

The Tatlmain granite has a peraluminous composition and plots in the volcanic arc field of discriminant diagrams (Fig. 10 b-d). Trace element and rare earth patterns also suggest a magmatic arc setting (Fig. 11 c,d). Primitive-mantle multi-element patterns for Tatlmain batholith (Fig. 11c) exhibit positive Zr anomalies similar to those of felsic volcanic rocks in the Little Salmon succession (Fig. 15c). The correspondence between the composition and age of the Tatlmain batholith and the base of Little Salmon succession strongly suggests that they are comagmatic.

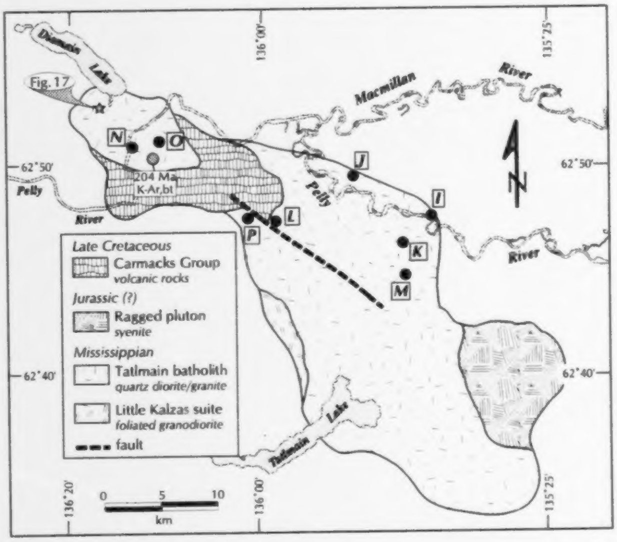

Diamain Lake
Fig. 17
Macmillan River
Pelly River
Tatlmain Lake
N
O
J
I
K
M
P
L
204 Ma K-Ar,bt
136°00'
135°25'
136°20'
62°50'
62°40'
Late Cretaceous
Carmacks Group volcanic rocks
Jurassic (?)
Ragged pluton syenite
Mississippian
Tatlmain batholith quartz diorite/granite
Little Kalzas suite foliated granodiorite
fault
0 5 10
km

Figure 16. Location map for geochemistry samples from Tatlmain batholith. Analytical data are presented in Table 4. K-Ar biotite date is from Stevens et al. (1982) and Tempelman-Kluit (1984). Location of outcrop displayed in Figure 17 is indicated.

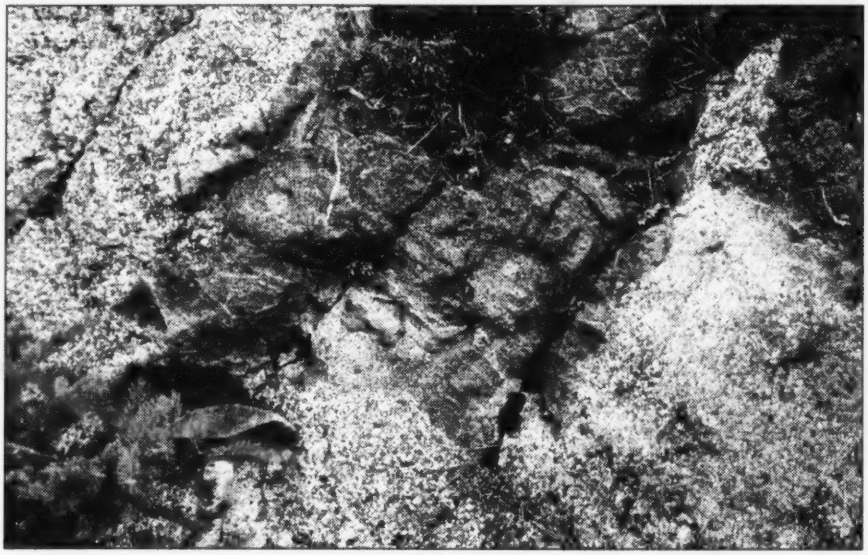


Figure 17. Xenolith of foliated granodiorite (Little Kalzas intrusive suite) in undeformed, coarse-grained granite of the Tatlmain batholith. Outcrop location is shown in Figure 16.

Near Little Salmon Lake, units underlying the Little Salmon succession (Drury unit and Snowcap assemblage) are intruded by plutons which have preliminary U-Pb ages similar to that of Tatlmain batholith (J.K. Mortensen, pers. comm., 2000). These intrusions are included in the Little Salmon suite. At the east end of Little Salmon Lake, a granodiorite pluton intrudes the Drury unit (Drury pluton; Fig. 12). Zircons from this pluton yielded a discordant U-Pb age of 353 ± 1.4 Ma (Oliver and Mortensen, 1998). Preliminary results on another sample from the Drury pluton suggest that its age may be somewhat younger (ca. 340 Ma; J.K. Mortensen, pers. comm., 2000). The Drury pluton consists of variably foliated, homogeneous, fine- to medium-grained, equigranular biotite ± hornblende granodiorite. Skarn is locally developed in calcareous rocks of the Drury unit near the contact with the pluton.

A large body of quartz diorite to granodiorite intrudes the Snowcap assemblage near the centre of Little Salmon Lake (Fig. 12). The rock is moderately to strongly foliated, fine- to medium-grained, and contains hornblende and, locally, biotite. Muscovite is a common constituent of this rock; it probably formed as a result of low grade metamorphism of original potassium-feldspar in the granodiorite. A skarn is present along the northern margin of this pluton; a nearby sample of hornblende granodiorite also contains traces of molybdenite.

A sill of very coarse-grained (pegmatitic), foliated hornblende tonalite is also included in Little Salmon intrusive suite. It consists almost exclusively of plagioclase and hornblende, with hornblende commonly occurring as crystals up to several centimetres long.

All intrusive bodies of the Little Salmon suite have peraluminous compositions (Fig. 10b) and trace element characteristics of volcanic arc magmas (Figs. 10 c,d, 11 e,f). Trace element and rare earth patterns for Little Salmon suite (Fig. 11 e,f) are similar to those of Tatlmain batholith (Fig. 11 c,d), and dacite of the Little Salmon succession (Fig. 15c). Granitoids of the Little Salmon suite are considered comagmatic with the Tatlmain batholith and subvolcanic to calc-alkaline rocks of the Little Salmon succession due to their similar chemistry and preliminary U-Pb ages.

DISCUSSION

Ongoing bedrock mapping, geochronological and geochemical studies have outlined two distinct magmatic suites within Yukon-Tanana Terrane in Glenlyon map area (Figs. 2, 3). The early to mid-Mississippian Little Kalzas suite (Fig. 3) consists primarily of calc-alkaline andesites and minor alkali basalts (Fig. 6), and subvolcanic diorites (Fig. 10) which are interpreted to have formed in a continental arc setting. The slightly younger Tatlmain/ Little Salmon suite (mid-Mississippian to early Pennsylvanian; Fig. 3) intrudes previously deformed rocks of Little Kalzas succession and represents a second arc cycle. It consists of calc-alkaline andesites and alkali basalts (Fig. 6), and subvolcanic intrusions ranging in composition from quartz diorite to granite (Fig. 10). Volcanic rocks from both the Little Kalzas and Little Salmon successions have mixed calc-alkaline and alkaline (OIB) geochemical signatures (Figs. 6, 7, 15). In the Little Kalzas succession, alkali basalt both underlies and overlies the calc-alkaline volcanic rocks. In the Little Salmon succession, alkali basalt appears to be laterally continuous with the calc-alkaline andesite (Fig. 12). The occurrence of alkaline rocks within continental arc sequences of Yukon-Tanana Terrane is most reasonably interpreted to indicate episodic rifting of the arc. It is also noteworthy that the two main pulses of arc magmatism documented here are punctuated by an episode of contractional deformation (Fig. 3; Colpron et al., 2000). Taken together, stratigraphic, structural, geochronological and geochemical data suggest that Yukon-Tanana Terrane originated in a dynamic continental arc setting which was punctuated by episodes of arc rifting and arc shortening.

IMPLICATIONS FOR VOLCANOGENIC MASSIVE SULPHIDE EXPLORATION

Little Salmon succession hosts a small sulphide occurrence at its base and has exhalative rocks (Mn chert) intercalated with alkali basalts higher up in the section (Figs. 3, 12). The geochemical data presented here clearly shows that arc magmatism in Yukon-Tanana Terrane of Glenlyon map area was punctuated by arc-rifting events. Episodes of arc rifting have been recognized as a significant factor in generation and preservation of volcanogenic massive sulphide deposits (e.g., van Staal et al., 1991; Syme et al., 1996). The occurrence of Mn-rich exhalative rocks in the rifted arc sequence at Little Salmon (Fig. 12) clearly shows that hydrothermal systems were operational during arc rifting. Occurrences of similar Mn-rich exhalite (of possible mid-Mississippian to early Pennsylvanian age) are scattered along the length of Yukon-Tanana Terrane in southern Yukon and northern British-Columbia (Fig. 1; Yukon MINFILE, 1997, 105C 017; Mihalynuk et al., 2000; Nelson et al., 2000), an area which, so far, has received little exploration attention on account of its complex and poorly understood geology. Ongoing studies along this belt are now providing an evolving stratigraphic context which can help focus exploration strategies in this largely under-explored host for volcanogenic massive sulphides (Nelson et al., 2000; Colpron and Yukon-Tanana Working Group, this volume).

COMPARISON WITH FINLAYSON LAKE DISTRICT

Volcanic rocks of the Little Kalzas succession are broadly coeval with felsic volcanic rocks hosting the Wolverine deposit (ca. 345 Ma; S.J. Piercey, pers. comm., 2000; Nelson et al., 2000; Colpron and Yukon-Tanana Working Group, this volume). However, the Little Kalzas succession represents a continental arc, whereas the Wolverine succession formed in a back-arc environment (Piercey et al., 2000). It is uncertain at present whether these tectonic environments shared a common paleogeographic setting. Granitoids from both the Little Kalzas intrusive suite, in Glenlyon area, and the Simpson Range plutonic suite, in Finlayson Lake district, have similar compositions (Piercey et al., 1999) and ages (Mortensen, 1992) and may provide the link between these two regions.

Perhaps the best possible link between Yukon-Tanana stratigraphy northeast of Tintina Fault and that of the terrane southwest of the fault lies in the apparent age and lithologic correspondence between the Pennsylvanian Boswell/Semenof succession (Tempelman-Kluit *in:* Gordey et al., 1991) and the Pennsylvanian section of the Finlayson Lake district (Murphy, this volume).

ACKNOWLEDGEMENTS

The results presented here are based on mapping and sampling of volcanic rocks in Glenlyon area over the past three field seasons, during which the assistance of Alana Rawlings, Melanie Reinecke and Reid Kennedy were appreciated. Discussions with Steve Piercey, Don Murphy, Jim Mortensen and Jan Peter have influenced various aspects of this project. The manuscript has benefited from critical reviews by Steve Piercey and Don Murphy, and editorial comments by Leyla Weston.

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***Table 1.** Geochemistry of mafic and intermediate volcanic rocks from the Little Kalzas succession.*

1 SAMPLE[1] unit[2]	2 98MC028B Pbslt	3 98MC029B Pbslt	4 98MC061A LKand	5 98MC066B LKand	6 98MC067 LKand	7 98MC086 LKand	8 98MC087 LKand	9 98MC088 LKand	10 98MC089 LKand	11 98MC091 LKand	12 98MC153 LKand	13 98MC156 LKand	14 98MC162B LKand	98MC172 LKbslt
SiO_2	47.42	46.37	66.97	54.97	59.17	58.18	69.82	53.36	64.60	53.25	50.32	71.22	55.87	47.75
Al_2O_3	12.37	15.61	14.60	16.29	18.48	15.37	14.17	17.11	15.04	15.55	16.74	12.12	16.60	16.14
Fe_2O_3	11.08	13.96	4.24	9.00	5.84	7.32	2.98	10.92	6.42	8.82	11.22	3.93	8.73	10.69
MnO	0.19	0.18	0.15	0.17	0.17	0.17	0.02	0.21	0.62	0.15	0.14	-0.01	0.14	0.17
MgO	4.72	5.23	1.99	3.92	1.84	2.57	0.77	3.90	1.32	4.57	7.89	0.73	4.64	6.55
CaO	6.31	3.55	3.05	8.55	4.55	4.95	0.15	4.53	1.35	6.47	1.61	0.37	3.58	7.80
Na_2O	5.27	4.77	3.09	2.76	3.82	1.04	4.62	5.17	3.16	2.84	4.55	0.68	2.23	2.85
K_2O	0.01	0.05	4.33	2.55	5.11	6.58	2.97	0.64	4.39	2.33	1.64	7.70	3.51	2.92
TiO_2	3.02	4.01	0.54	0.83	0.83	0.89	0.64	1.11	0.79	0.81	1.23	0.57	1.06	2.24
P_2O_5	0.75	1.18	0.23	0.42	0.34	0.30	0.14	0.27	0.38	0.37	0.41	0.28	0.38	0.63
LOI	9.07	5.55	1.34	1.31	0.70	2.08	2.97	2.90	1.89	4.52	4.08	1.21	3.25	3.04
TOTAL	100.20	100.47	100.55	100.77	100.86	99.44	99.26	100.11	99.96	99.68	99.81	98.82	99.99	100.75
V	126	161	130	237	214	221	176	244	224	192	223	101	190	240
Cr	-10	-10	43	11	90	76	52	-10	59	30	539	49	26	104
Co	21	29	9	161	24	17	197	26	18	166	32	9	18	46
Ni	-10	-10	-10	39	-10	-10	115	-10	35	70	343	-10	-10	69
Cu	20	22	22	31	75	39	26	123	-10	49	64	17	25	54
Zn	68	83	49	80	242	80	72	94	620	90	126	45	155	121
Ga	19	27	15	20	22	18	16	19	18	18	19	13	19	20
Ge	1.5	1.3	1.3	1.9	1.3	1.4	1.2	0.9	1.9	1.3	2.2	1.4	1.7	1.5
As	-5	-5	-5	7	-5	-5	65	-5	17	10	-5	-5	6	-5
Rb	1	2	107	68	127	185	81	15	110	36	63	157	77	69
Sr	240	154	112	828	318	108	74	135	192	638	87	46	499	372
Y	36.0	47.0	16.0	24.0	23.0	19.0	13.0	28.0	28.0	23.0	26.0	15.0	25.0	30.0
Zr	267	190	129	118	148	126	118	129	125	110	128	96	150	168
Nb	70.0	76.0	12.0	8.5	13.0	12.0	11.0	4.0	10.0	8.2	16.0	9.8	17.0	80.0
Mo	0	1	0	6	0	1	52	1	0	6	1	0	0	12
Ag	-0.5	-0.5	-0.5	-0.5	-0.5	-0.5	-0.5	0.5	-0.5	-0.5	-0.5	-0.5	-0.5	-0.5
In	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1
Sn	2.0	2.0	1.0	1.0	1.2	0.9	4.4	4.7	1.2	0.9	1.3	0.9	1.4	1.6
Sb	1.13	0.88	0.53	1.79	0.49	0.32	3.21	0.58	1.41	4.49	0.75	1.04	0.73	0.68
Cs	-0.1	0.1	4.8	3.5	6.5	8.6	2.0	1.1	3.1	0.8	4.9	3.0	4.5	1.9
Ba	51	32	827	1322	1786	995	1228	606	839	1681	229	1261	1652	611
Hf	5.9	4.5	3.2	3.1	3.7	3.2	2.9	3.5	3.0	2.8	3.2	2.5	3.7	4.0
Ta	4.36	5.35	0.80	0.51	0.88	0.75	0.72	0.25	0.65	0.48	0.90	0.69	1.02	4.42
W	0.5	3.4	0.3	1.7	0.7	0.5	5.6	1.5	0.6	1.6	0.5	0.8	0.8	0.5
Tl	-0.05	0.06	0.45	0.44	0.50	0.57	2.46	0.16	0.66	1.02	0.30	0.59	0.31	0.86
Pb	-5	6	8	27	37	5	285	-5	49	51	6	-5	10	1
Bi	-0.05	0.13	0.12	0.25	0.14	0.07	0.89	0.21	0.09	0.22	0.19	0.07	0.09	0.00
Th	4.82	5.90	7.78	5.27	7.28	5.39	5.87	2.33	5.19	5.12	6.59	5.58	5.80	6.36
U	1.04	2.32	2.98	2.03	2.04	2.10	2.41	0.85	1.97	1.96	1.88	1.34	2.52	1.30
La	52.1	63.6	22.2	21.3	25.4	23.7	39.9	14.3	20.5	20.5	20.2	17.6	24.0	44.8
Ce	104.0	129.0	41.4	44.4	48.8	46.4	66.8	32.9	42.1	41.3	42.6	34.8	50.2	77.3
Pr	12.16	15.63	4.78	5.43	5.67	5.47	6.91	4.59	5.05	4.99	5.58	3.97	6.13	8.30
Nd	51.0	67.1	18.9	22.4	23.5	23.0	24.8	21.9	21.8	21.1	24.9	16.4	26.1	33.0
Sm	9.95	13.30	3.61	4.77	4.89	4.83	3.85	5.26	4.61	4.37	5.43	3.44	5.50	6.46
Eu	3.08	3.83	0.91	1.23	1.22	1.24	1.08	1.48	1.22	1.04	1.66	0.84	1.46	2.08
Gd	8.64	11.50	3.19	4.48	4.32	4.33	2.82	4.93	4.46	4.60	5.18	3.25	5.18	6.18
Tb	1.31	1.66	0.46	0.69	0.68	0.60	0.35	0.82	0.68	0.66	0.77	0.49	0.77	0.96
Dy	6.60	8.61	2.51	3.95	3.84	3.24	1.94	4.73	3.95	3.61	4.27	2.71	4.19	5.30
Ho	1.18	1.57	0.49	0.77	0.75	0.62	0.41	0.96	0.79	0.72	0.82	0.50	0.80	0.99
Er	3.20	4.33	1.52	2.35	2.31	1.81	1.31	2.92	2.42	2.15	2.38	1.49	2.35	2.88
Tm	0.444	0.600	0.237	0.330	0.354	0.267	0.209	0.438	0.358	0.314	0.340	0.220	0.318	0.414
Yb	2.56	3.36	1.46	2.11	2.22	1.69	1.37	2.70	2.26	1.99	2.11	1.35	1.97	2.47
Lu	0.344	0.460	0.237	0.328	0.368	0.258	0.222	0.434	0.375	0.300	0.311	0.212	0.285	0.360
Easting[3]	**454070**	**453904**	**461435**	**459960**	**459776**	**461850**	**462254**	**463518**	**463712**	**464840**	**466464**	**466841**	**467851**	**470241**
Northing	**6979247**	**6979016**	**6978786**	**6979788**	**6980105**	**6976099**	**6975747**	**6974587**	**6974532**	**6974783**	**6970635**	**6972325**	**6969422**	**6969873**

Analytical Method: Samples were prepared using a ceramic mill and analyzed for major, trace and rare-earth elements (REE) at Activation Laboratories in Ancaster, Ontario. Major element concentrations were determined by fusion X-ray fluorescence (XRF). Trace elements and REE were analyzed by inductively coupled plasma mass spectrometry (ICP-MS) at research detection limits.

Notes: [1]Samples are located with arabic numerals in Figure 4. [2]Unit and rock codes: *P* = Pelmac unit, *LK* = Little Kalzas succession. *bslt* = basalt, *and* = andesite. [3]UTM Zone 8, NAD27.

Table 2. *Geochemistry of mafic and intermediate volcanic rocks from Little Salmon succession.*

SAMPLE[1] unit[2]	15 99MC027-3 LSand	16 99MC028 LSand	17 99MC045 LSand	18 99MC081 LSand	19 99MC153 LSand	20 99MC030 LSbslt	21 99MC109 LStuff	22 00MC016 LSand	23 00MC023 LSand	24 00MC035 LSand
SiO_2	65.93	65.33	60.50	53.70	58.53	49.20	66.28	58.41	71.78	54.57
Al_2O_3	12.28	14.66	14.68	16.43	14.38	15.21	13.40	14.10	11.72	15.96
Fe_2O_3	7.88	7.14	9.68	11.34	9.41	12.79	6.93	9.55	5.15	11.46
MnO	0.16	0.12	0.19	0.22	0.19	0.17	0.15	0.16	0.12	0.22
MgO	2.95	2.25	3.93	4.09	3.10	4.05	2.11	3.20	2.53	3.23
CaO	4.09	2.37	3.24	5.56	5.86	8.13	1.22	5.96	1.42	5.56
Na_2O	2.70	1.60	4.22	5.60	3.46	4.60	5.57	2.86	2.90	3.50
K_2O	1.06	3.84	0.59	0.77	1.16	1.16	1.11	0.87	1.57	2.08
TiO_2	0.86	0.73	0.95	1.09	0.86	3.20	0.84	0.86	0.61	1.02
P_2O_5	0.21	0.24	0.22	0.24	0.20	0.51	0.17	0.18	0.14	0.31
LOI	2.77	2.38	2.65	1.79	3.37	1.92	1.10	2.51	2.24	2.39
TOTAL	100.89	100.66	100.83	100.82	100.51	100.93	98.89	98.65	100.18	100.30
V	190	100	255	209	259	312	105	181	108	305
Cr	-20	59	-20	-20	-20	-20	-20	-20	65	-20
Co	16	11	24	8	24	36	14	19	11	28
Ni	-15	29	16	-15	18	31	-15	-20	-20	-20
Cu	97	61	128	36	158	49	52	75	53	95
Zn	86	82	87	-30	87	74	65	109	103	93
Ga	14	18	17	4	13	18	5	19	16	21
Ge	1.3	1.5	1.4	-0.5	1.8	1.4	0.6	1.4	0.8	1.5
As	-5	-5	-5	-5	-5	-5	-5	-5	7	-5
Rb	27	125	9	11	15	22	22	15	45	35
Sr	277	313	945	278	385	261	41	588	92	359
Y	25.3	33.2	28.3	24.6	20.9	46.6	16.2	24.1	21.0	29.3
Zr	117	203	121	104	98	282	96	119	123	114
Nb	4.3	13.0	4.3	3.0	3.4	25.8	2.8	3.3	6.8	1.7
Mo	-2	-2	-2	-2	-2	-2	-2	-2	-2	-2
Ag	-0.5	-0.5	-0.5	-0.5	-0.5	-0.5	-0.5	-0.5	-0.5	-0.5
In	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1
Sn	-1.0	2.0	-1.0	-1.0	-1.0	2.0	-1.0	1.1	1.5	1.1
Sb	0.70	0.20	0.50	-0.20	0.40	0.60	-0.20	0.71	0.59	1.19
Cs	1.6	4.7	0.5	0.8	0.4	0.5	0.9	0.4	1.7	0.7
Ba	791	3630	369	403	1040	222	575	536	1250	1120
Hf	3.0	5.2	3.2	3.1	3.0	6.2	2.6	3.5	3.7	3.6
Ta	0.30	0.90	0.20	0.20	0.20	1.70	0.20	0.30	0.68	0.18
W	0.2	1.0	-0.2	-0.2	0.2	0.2	-0.2	-0.5	-0.5	-0.5
Tl	0.15	0.44	-0.05	-0.05	0.11	0.06	0.10	0.07	0.23	0.13
Pb	-5	10	6	-5	5	5	-5	13	7	10
Bi	-0.06	0.14	-0.06	-0.06	0.06	-0.06	-0.06	0.58	0.18	0.32
Th	1.79	11.10	1.85	1.67	1.71	1.80	1.37	2.07	5.33	2.28
U	0.66	3.46	0.69	0.61	0.61	0.46	0.42	0.65	1.68	0.67
La	10.3	35.4	11.6	13.3	12.2	20.4	8.5	11.8	17.0	14.5
Ce	23.1	69.0	26.5	30.3	28.6	47.6	18.5	26.9	34.3	36.5
Pr	3.31	8.14	3.73	4.25	3.98	6.56	2.64	3.79	4.15	4.94
Nd	14.9	31.9	17.0	19.8	18.4	29.6	12.0	18.1	17.3	24.0
Sm	3.69	6.52	4.12	4.73	4.37	7.10	3.09	4.44	3.77	5.56
Eu	1.11	1.48	1.44	1.57	1.50	2.63	0.94	1.33	0.97	1.85
Gd	3.94	5.88	4.36	4.75	4.41	7.86	3.28	4.12	3.44	5.07
Tb	0.73	1.02	0.79	0.79	0.74	1.44	0.59	0.78	0.64	0.95
Dy	4.30	5.73	4.62	4.48	4.23	8.35	3.45	4.57	3.80	5.50
Ho	0.90	1.16	0.96	0.87	0.81	1.67	0.65	0.92	0.76	1.11
Er	2.77	3.52	2.96	2.54	2.43	5.01	1.84	2.72	2.30	3.20
Tm	0.418	0.533	0.452	0.389	0.362	0.707	0.273	0.393	0.336	0.469
Yb	2.68	3.43	2.87	2.54	2.42	4.44	1.73	2.65	2.29	2.97
Lu	0.400	0.524	0.430	0.361	0.346	0.637	0.267	0.392	0.330	0.439
Easting[3]	**521633**	**522302**	**519972**	**518588**	**516734**	**524585**	**511508**	**512505**	**509479**	**511140**
Northing	**6895854**	**6896054**	**6896492**	**6897686**	**6905239**	**6896178**	**6902265**	**6907918**	**6908078**	**6907253**

Analytical Method: Samples were prepared using a ceramic mill and analyzed for major, trace and rare-earth elements (REE) at Activation Laboratories in Ancaster, Ontario. Major element concentrations were determined by fusion X-ray fluorescence (XRF). Trace elements and REE were analyzed by inductively coupled plasma mass spectrometry (ICP-MS) at research detection limits.

Notes: [1]Samples are located with arabic numerals in Figure 12. [2]Unit and rock codes: *LS* = Little Salmon succession, *and* = andesite, *bslt* = basalt, *tuff* = tuff of intermediate compostion.
[3]UTM Zone 8, NAD27.

Table 2. *Continued.*

SAMPLE[1] unit[2]	25 MRT025 LSbslt	26 MRT028B LSbslt	27 MRT013 LSbslt	28 MRT018 LSbslt	29 MRT031 LSbslt	30 00MC042 LSbslt	31 00MC045 LSbslt	32 00MC057 LSbslt	33 00MC061 LSbslt	34 00MC124 LShbsl	35 00MC129 LSpbsl
SiO_2	44.80	44.79	46.31	45.87	45.71	48.58	47.35	43.90	46.57	43.07	42.59
Al_2O^3	17.13	16.29	14.93	16.14	17.72	19.02	17.33	16.02	17.30	16.15	18.78
Fe_2O^3	11.45	9.97	11.01	13.08	12.52	12.17	12.49	10.65	11.51	10.12	9.68
MnO	0.18	0.21	0.23	0.21	0.38	0.14	0.15	0.20	0.18	0.15	0.21
MgO	6.73	4.40	7.15	4.46	4.81	2.98	4.64	8.39	4.60	8.17	3.81
CaO	9.84	11.70	7.30	6.00	9.06	5.16	5.06	9.73	7.82	11.76	11.79
Na_2O	2.03	2.14	2.99	4.26	1.93	2.85	4.79	1.30	3.35	1.30	3.48
K_2O	0.47	1.19	0.03	1.33	1.69	2.30	0.61	1.84	0.68	1.81	0.65
TiO_2	2.31	1.95	2.31	2.22	2.16	2.37	2.87	1.95	2.12	2.00	1.48
P_2O_5	0.63	0.86	0.55	0.36	0.72	0.97	0.73	0.58	0.71	0.52	0.36
LOI	3.80	5.20	6.77	5.18	3.82	2.87	3.46	3.99	3.92	3.71	7.26
TOTAL	99.36	98.70	99.58	99.09	100.49	99.41	99.48	98.56	98.75	98.77	100.10
V	206	258	198	220	248	216	250	213	193	242	145
Cr	183	296	95	331	406	326	53	372	26	154	122
Co	33	38	32	45	35	45	42	35	30	34	36
Ni	52	105	53	95	92	90	-20	250	59	78	-20
Cu	19	47	28	-10	79	49	20	56	57	64	32
Zn	61	60	69	106	117	217	124	71	62	55	145
Ga	16	15	15	11	18	19	22	20	20	17	18
Ge	1.7	1.7	1.3	1.4	3.2	1.8	1.6	1.0	2.1	1.9	1.1
As	-5	-5	-5	-5	1	7	-5	-5	-5	8	-5
Rb	11	25	-2	29	37	45	14	36	14	33	11
Sr	629	1130	539	168	674	436	775	714	976	956	665
Y	28.3	23.6	30.6	42.2	34.9	61.8	39.2	24.8	28.6	27.1	25.5
Zr	184	164	192	144	199	106	256	149	162	129	139
Nb	68.0	46.2	47.7	71.4	95.9	43.8	44.6	62.2	79.8	48.5	21.9
Mo	-2	-2	-2	-2	-2	-2	-2	-2	-2	-2	-2
Ag	-0.5	-0.5	-0.5	-0.5	-0.5	-0.5	-0.5	-0.5	-0.5	-0.5	-0.5
In	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1
Sn	2.0	1.0	1.0	19.0	2.0	1.2	2.0	1.4	1.5	1.2	1.4
Sb	0.70	0.40	-0.20	0.60	0.95	1.32	0.68	1.13	1.98	2.20	0.68
Cs	0.5	0.6	-0.1	1.1	1.6	2.2	0.7	1.1	0.7	0.7	0.6
Ba	147	240	41	364	568	374	181	582	318	547	97
Hf	4.3	3.9	4.3	3.6	4.5	3.2	6.3	3.9	3.5	3.2	3.3
Ta	4.10	2.90	3.00	4.60	5.45	4.12	4.08	5.42	6.34	4.24	2.06
W	0.4	0.2	-0.2	0.5	0.5	4.2	-0.5	-0.5	0.6	-0.5	-0.5
Tl	0.08	0.11	-0.05	0.36	0.53	0.68	0.08	0.16	0.10	0.07	0.07
Pb	-5	-5	-5	-5	-5	-5	5	-5	-5	-5	-5
Bi	-0.06	-0.06	-0.06	-0.06	-0.06	0.13	0.12	-0.10	0.13	-0.10	-0.10
Th	3.62	3.08	2.78	4.06	5.45	3.67	4.27	5.59	5.33	4.36	2.30
U	1.16	0.58	0.84	0.72	1.08	1.34	1.04	1.53	1.12	0.97	0.59
La	36.4	27.7	28.3	46.5	52.5	66.5	37.9	42.2	52.7	35.0	21.7
Ce	67.4	49.7	53.4	65.6	86.0	71.3	72.7	76.5	92.3	62.9	38.2
Pr	7.83	5.75	6.33	9.61	9.77	13.88	8.31	8.20	9.85	7.01	4.24
Nd	31.3	23.4	26.0	39.0	37.6	57.8	35.6	33.9	38.5	28.4	17.9
Sm	6.24	4.92	5.48	7.48	7.07	11.01	7.47	6.44	6.99	5.69	3.78
Eu	2.31	1.81	2.14	2.80	2.64	4.05	2.70	2.27	2.56	2.16	1.45
Gd	5.92	4.90	5.70	7.71	6.77	11.02	7.63	5.50	6.27	5.56	3.77
Tb	0.99	0.81	1.03	1.18	1.08	1.89	1.30	0.93	1.07	0.90	0.67
Dy	5.40	4.67	5.65	6.72	5.87	10.78	7.41	5.06	5.64	5.42	4.19
Ho	1.01	0.86	1.10	1.30	1.13	2.09	1.45	0.93	1.03	1.04	0.85
Er	2.85	2.45	3.08	3.61	3.13	5.79	4.15	2.65	2.90	2.88	2.56
Tm	0.402	0.352	0.442	0.483	0.438	0.742	0.593	0.347	0.381	0.401	0.370
Yb	2.61	2.24	2.87	3.02	2.83	4.45	3.77	2.21	2.37	2.63	2.30
Lu	0.362	0.323	0.402	0.432	0.405	0.625	0.542	0.303	0.334	0.369	0.325
Easting[3] **Northing**	**507275** **6909940**	**506507** **6909340**	**506541** **6907594**	**507052** **6907914**	**506543** **6908532**	**507520** **6908527**	**507146** **6907726**	**506634** **6908337**	**506342** **6909909**	**503363** **6910206**	**506853** **6907685**

Analytical Method: Samples were prepared using a ceramic mill and analyzed for major, trace and rare-earth elements (REE) at Activation Laboratories in Ancaster, Ontario. Major element concentrations were determined by fusion X-ray fluorescence (XRF). Trace elements and REE were analyzed by inductively coupled plasma mass spectrometry (ICP-MS) at research detection limits.

Notes: [1]Samples are located with arabic numerals in Figure 12. [2]Unit and rock codes: *LS* = Little Salmon succession, *bslt* = basalt, *hbsl* = hornblende-phyric basalt, *pbsl* = plagioclase-phyric basalt. [3]UTM Zone 8, NAD27.

Table 3. Geochemistry of felsic volcanic rocks from Little Kalzas and Little Salmon successions.

SAMPLE[1] unit[2]	i 98MC063 LKrhy	ii 98MC125 LKtuff	iii 99MC001a LSqfp	iii 99MC001b LSqfp	iii 99MC001c LSqfp	iv 99MC156 LSqfp	v 99MC027-2 LSdac	vi 99MC090 LSdac
SiO_2	76.03	75.19	70.94	73.53	68.82	68.55	69.25	66.85
Al_2O_3	12.93	13.56	15.86	13.29	14.67	13.68	14.00	15.26
Fe_2O_3	0.94	1.31	1.16	1.15	1.19	1.98	4.61	4.55
MnO	0.03	-0.01	0.02	0.03	0.04	0.06	0.09	0.10
MgO	1.00	0.85	1.32	1.18	1.42	0.84	1.22	1.42
CaO	0.41	0.04	1.69	2.09	3.06	3.60	3.06	1.33
Na_2O	1.58	0.09	1.19	2.66	0.71	2.73	1.52	5.22
K_2O	6.82	6.40	4.27	2.51	4.30	2.70	3.02	2.40
TiO_2	0.11	0.12	0.36	0.27	0.30	0.28	0.49	0.46
P_2O_5	0.03	0.04	0.07	0.06	0.08	0.07	0.09	0.16
LOI	0.88	1.79	3.17	3.13	4.30	4.06	1.79	0.84
TOTAL	100.77	99.39	100.05	99.93	98.86	98.56	99.15	98.59
V	9	-5	33	28	30	44	47	48
Cr	-10	-10	-20	-20	-20	27	31	37
Co	1	-1	2	-1	-1	2	4	6
Ni	-10	-10	-15	-15	-15	-15	-15	-15
Cu	-10	-10	-10	-10	-10	-10	26	16
Zn	27	21	-30	-30	-30	-30	51	60
Ga	14	17	17	14	16	10	20	13
Ge	1.1	0.9	0.8	1.1	1.1	1.3	1.5	1.2
As	-5	-5	-5	-5	-5	-5	-5	5
Rb	175	151	129	84	129	79	99	77
Sr	96	20	78	75	92	101	378	115
Y	19.0	27.0	15.2	20.5	15.1	17.4	32.2	24.3
Zr	138	154	203	160	164	157	233	266
Nb	11.0	13.0	14.6	11.8	11.1	11.5	11.8	15.0
Mo	0	0	-2	-2	-2	-2	-2	-2
Ag	-0.5	-0.5	-0.5	-0.5	-0.5	-0.5	-0.5	-0.5
In	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1
Sn	-0.5	2.1	3.0	2.0	3.0	2.0	5.0	2.0
Sb	0.66	0.13	-0.20	-0.20	-0.20	-0.20	0.60	-0.20
Cs	1.9	1.8	2.8	1.9	2.9	2.1	1.7	2.5
Ba	1257	2615	797	511	771	838	4000	1540
Hf	4.1	4.3	5.1	4.0	4.3	4.0	5.9	6.9
Ta	0.93	1.09	1.10	0.90	0.90	1.00	0.90	1.10
W	0.3	9.7	0.9	0.7	0.8	0.6	1.0	0.6
Tl	0.40	0.35	0.28	0.31	0.44	0.28	0.44	0.33
Pb	34	-5	-5	-5	8	-5	12	14
Bi	0.06	0.11	0.08	-0.06	0.27	-0.06	0.14	0.12
Th	13.10	14.70	8.82	7.57	8.49	8.11	10.60	19.20
U	2.39	3.11	1.65	1.36	1.71	1.83	3.74	5.22
La	30.3	36.2	16.7	17.0	26.5	19.9	31.9	43.8
Ce	55.6	66.4	32.5	33.9	49.1	40.6	61.5	81.8
Pr	6.07	6.99	3.59	3.84	5.23	4.76	7.46	8.61
Nd	22.6	25.7	13.2	14.2	18.4	18.2	28.5	30.5
Sm	4.26	4.95	2.53	2.85	3.44	3.56	5.80	5.59
Eu	0.72	0.67	0.70	0.68	1.02	0.89	1.12	1.10
Gd	3.65	4.50	2.37	2.55	2.89	3.06	5.28	4.83
Tb	0.55	0.73	0.41	0.48	0.47	0.54	0.94	0.75
Dy	3.08	4.31	2.40	3.08	2.66	2.92	5.48	4.27
Ho	0.63	0.87	0.50	0.66	0.53	0.58	1.10	0.82
Er	2.08	2.78	1.59	2.11	1.63	1.83	3.36	2.51
Tm	0.351	0.452	0.248	0.332	0.258	0.289	0.509	0.412
Yb	2.22	2.83	1.79	2.22	1.81	2.08	3.22	2.74
Lu	0.384	0.475	0.274	0.352	0.309	0.318	0.478	0.404
Easting[3]	**460677**	**467222**	**520405**	**520405**	**520405**	**519543**	**521633**	**520669**
Northing	**6979195**	**6976148**	**6895490**	**6895490**	**6895490**	**6895886**	**6895854**	**6897517**

Analytical Method: Samples were prepared using a ceramic mill and analyzed for major, trace and rare-earth elements (REE) at Activation Laboratories in Ancaster, Ontario. Major element concentrations were determined by fusion X-ray fluorescence (XRF). Trace elements and REE were analyzed by inductively coupled plasma mass spectrometry (ICP-MS) at research detection limits.

Notes: [1]Samples are located with roman numerals in Figures 4 and 12. [2]Unit and rock codes: *LK* = Little Kalzas succession, *LS* = Little Salmon succession, *rhy* = rhyolite, *tuff* = rhyolitic tuff, *qfp* = quartz-feldspar porphyry, dac = dacite. [3]UTM Zone 8, NAD27.

Table 4. *Geochemistry of Mississippian granitoids from Glenlyon map area (105L).*

SAMPLE[1] unit[2]	A 98MC035 LKd	B 98MC111 LKt	C 98MC101A LKd	C 98MC101C LKd	C 98MC101D LKd	D 98MC102 LKd	E 98MC104 LKd	F 98MC108 LKd	G 98MC119 LKd	H 98MC196A LKmg	H 98MC196D LKmg	I 98MC188 Ttlm	J 98MC190 Ttlm
SiO_2	66.86	69.14	55.45	53.91	70.84	61.90	53.34	62.00	59.05	75.74	57.56	63.76	64.41
Al_2O_3	14.31	14.43	12.40	14.51	14.33	15.44	9.02	15.73	15.81	10.29	14.65	16.85	17.33
Fe_2O_3	3.90	4.47	8.40	8.70	2.78	6.76	8.68	7.58	7.94	2.37	6.52	4.81	5.20
MnO	0.14	0.08	0.17	0.15	0.04	0.12	0.21	0.12	0.14	0.05	0.11	0.10	0.12
MgO	1.59	1.04	10.26	8.39	0.79	2.44	12.48	2.15	4.28	1.22	2.13	1.38	1.23
CaO	3.59	4.31	8.12	8.85	3.61	5.46	12.16	5.83	7.59	2.60	4.50	4.87	4.20
Na_2O	3.86	3.22	1.46	1.36	5.07	2.62	1.71	3.05	2.13	4.13	1.92	3.88	3.31
K_2O	2.01	1.44	1.44	0.97	0.52	0.78	0.21	1.32	0.44	1.57	6.01	1.76	2.54
TiO_2	0.40	0.38	0.35	0.43	0.27	0.55	0.26	0.66	0.40	0.38	0.52	0.46	0.51
P_2O_5	0.16	0.08	0.08	0.11	0.06	0.15	0.05	0.14	0.04	0.07	0.36	0.15	0.19
LOI	4.17	1.32	2.41	3.18	1.91	2.27	2.49	1.51	3.01	2.44	6.11	1.30	1.95
TOTAL	100.99	99.90	100.53	100.56	100.23	98.49	100.61	100.09	100.82	100.85	100.39	99.32	100.99
V	79	51	165	162	33	119	256	106	184	35	80	55	42
Cr	31	-10	371	312	-10	36	308	-10	-10	24	27	-10	-10
Co	9	8	39	15	5	14	41	13	26	5	13	7	8
Ni	27	-10	237	28	-10	11	56	54	-10	13	24	10	-10
Cu	31	11	-10	36	12	35	26	-10	-10	-10	29	-10	-10
Zn	37	49	68	12	29	66	62	55	72	37	96	46	81
Ga	14	15	12	9	15	18	8	15	16	11	17	16	19
Ge	1.3	1.2	1.2	-0.5	1.0	1.1	1.5	1.0	1.3	0.8	1.3	1.2	1.3
As	7	-5	-5	-5	-5	-5	-5	-5	-5	6	7	-5	-5
Rb	67	38	39	25	11	22	4	40	11	40	263	48	91
Sr	137	163	95	128	181	236	87	250	170	133	151	277	302
Y	12.0	26.0	10.0	15.0	19.0	18.0	10.0	15.0	18.0	16.0	21.0	17.0	11.0
Zr	95	126	35	45	148	56	16	61	48	321	256	95	86
Nb	8.1	7.1	1.6	1.8	6.9	5.7	1.0	8.3	2.3	9.0	29.0	5.8	6.8
Mo	0	0	0	0	0	0	1	0	0	0	1	0	0
Ag	-0.5	-0.5	-0.5	-0.5	-0.5	-0.5	-0.5	-0.5	-0.5	-0.5	-0.5	-0.5	-0.5
In	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1
Sn	0.6	1.2	-0.5	-0.5	0.5	1.2	-0.5	0.6	0.8	0.9	3.8	0.9	1.3
Sb	0.31	0.67	0.63	0.21	0.84	0.59	0.75	0.80	0.90	0.49	2.59	0.09	0.59
Cs	1.5	0.6	0.4	0.4	0.4	0.2	-0.1	0.3	0.1	0.7	8.1	1.4	10.0
Ba	434	602	409	299	248	258	37	568	160	384	696	571	855
Hf	2.5	3.5	1.1	1.3	3.8	1.6	0.5	1.8	1.6	8.2	6.0	2.6	2.3
Ta	0.61	0.51	0.12	0.14	0.53	0.43	0.06	0.58	0.14	0.67	2.17	0.39	0.68
W	1.6	0.4	0.3	0.2	0.3	0.4	0.4	0.5	0.2	0.3	3.7	-0.2	-0.2
Tl	0.31	0.22	0.20	0.06	0.05	0.10	0.65	0.20	0.08	0.24	2.75	0.19	0.73
Pb	-5	5	-5	-5	6	6	-5	-5	-5	7	33	-5	9
Bi	0.13	0.09	0.14	0.09	0.10	0.13	0.24	0.24	0.08	0.13	0.49	-0.05	-0.05
Th	5.59	6.67	2.46	2.23	8.84	5.23	1.09	7.91	2.14	15.60	47.80	4.13	1.85
U	1.73	1.98	0.66	0.57	2.13	1.47	0.26	1.36	0.51	2.00	5.49	0.52	0.86
La	13.7	16.4	5.4	6.3	22.2	16.0	3.6	17.5	6.7	31.9	63.8	13.9	10.3
Ce	26.0	32.6	9.4	13.1	40.7	32.4	7.6	29.8	15.1	65.0	117.0	26.3	20.4
Pr	2.83	3.76	1.02	1.64	4.31	3.73	1.00	3.10	1.90	7.12	11.70	2.98	2.35
Nd	11.7	15.1	4.3	7.0	15.9	14.7	4.6	11.6	8.3	25.8	40.8	11.9	9.4
Sm	2.25	3.29	1.11	1.78	2.96	3.09	1.20	2.19	2.10	4.28	6.34	2.56	1.82
Eu	0.62	0.80	0.36	0.53	0.67	0.82	0.30	0.79	0.62	0.76	1.13	0.90	1.02
Gd	2.09	3.61	1.40	2.31	2.99	2.98	1.53	2.57	2.54	3.45	4.93	2.51	1.88
Tb	0.33	0.62	0.25	0.36	0.46	0.48	0.24	0.35	0.43	0.48	0.66	0.42	0.28
Dy	1.90	3.84	1.54	2.25	2.69	2.85	1.47	2.16	2.75	2.58	3.34	2.49	1.62
Ho	0.37	0.80	0.33	0.48	0.57	0.58	0.30	0.44	0.59	0.50	0.61	0.50	0.33
Er	1.14	2.62	1.05	1.58	1.87	1.84	0.95	1.48	1.98	1.52	1.86	1.63	1.05
Tm	0.181	0.402	0.162	0.242	0.297	0.278	0.138	0.239	0.308	0.242	0.286	0.260	0.162
Yb	1.13	2.60	1.02	1.56	1.94	1.78	0.87	1.61	2.00	1.55	1.85	1.67	1.05
Lu	0.193	0.431	0.179	0.260	0.331	0.284	0.132	0.296	0.352	0.244	0.284	0.265	0.167
Easting[3] **Northing**	**454681** **6977134**	**468695** **6978122**	**467101** **6980418**	**467101** **6980418**	**467101** **6980418**	**466921** **6980434**	**466687** **6979916**	**469184** **6978820**	**466184** **6980951**	**472019** **6974068**	**472019** **6974068**	**464186** **6962848**	**457289** **6966486**

Analytical Method: Samples were prepared using a ceramic mill and analyzed for major, trace and rare-earth elements (REE) at Activation Laboratories in Ancaster, Ontario. Major element concentrations were determined by fusion X-ray fluorescence (XRF). Trace elements and REE were analyzed by inductively coupled plasma mass spectrometry (ICP-MS) at research detection limits.

Notes: [1]Samples are located with capital letters in Figures 4 and 16. [2]Unit and rock codes *LK* = Little Kalzas suite, *d* = *granodiorite*, *t* = tonalite, *mg* = K-feldspar megacrystic phases, *Ttlm* = Tatlmain batholith (quartz diorite to granite). [3]UTM Zone 8, NAD27.

Table 4. Continued.

SAMPLE[1] unit[2]	K 98MC195 Ttlm	L 99MC065 Ttlm	M 00TTL001 Ttlm	N 00TTL003 Ttlm	O 00TTL007 Ttlm	P 00TTL010 Ttlm	Q 99MC070 LSpg	R 99MC034 LSgd	S 99MC035 LSgd	T 99MC036 LSgd	U 99MC014 LSqd	V 00MC106 LSqd	W 00MC214 LSqd	X 00MC215 LSqd
SiO_2	59.80	66.43	76.33	74.56	73.44	74.55	64.50	62.56	54.43	72.57	66.13	62.36	66.66	74.26
Al_2O_3	16.79	13.97	12.63	13.52	14.05	13.35	13.28	16.24	17.32	14.06	14.60	15.44	14.59	12.82
Fe_2O_3	5.77	3.21	2.39	2.21	2.26	2.28	6.10	6.79	7.92	2.80	5.41	6.07	4.77	3.09
MnO	0.10	0.09	0.04	0.05	0.05	0.05	0.11	0.13	0.13	0.04	0.10	0.12	0.08	0.04
MgO	2.99	1.05	0.53	0.43	0.43	0.64	3.70	2.07	5.00	0.41	2.22	2.50	1.82	1.03
CaO	6.52	1.61	2.33	1.69	1.98	1.91	2.87	5.84	8.07	1.93	4.11	5.30	3.07	3.71
Na_2O	3.14	3.72	2.97	3.62	3.88	3.43	3.87	2.95	2.99	3.94	2.95	2.30	4.17	3.85
K_2O	1.90	3.23	2.48	3.22	3.07	3.03	2.10	1.49	1.32	2.95	1.76	2.05	1.71	0.25
TiO_2	0.58	0.35	0.24	0.19	0.22	0.25	0.40	0.67	0.85	0.24	0.43	0.47	0.58	0.33
P_2O_5	0.13	0.10	0.06	0.06	0.07	0.06	0.10	0.15	0.16	0.05	0.10	0.11	0.16	0.07
LOI	2.05	6.92	0.49	0.76	0.62	0.95	3.64	1.69	2.18	0.97	2.52	1.98	2.79	0.93
TOTAL	99.77	100.68	100.48	100.31	100.07	100.50	100.67	100.60	100.38	99.96	100.30	98.70	100.41	100.39
V	145	40	36	13	12	27	126	117	193	10	103	134	75	50
Cr	25	-20	-20	-20	-20	-20	24	-20	-20	-20	28	-20	-20	-20
Co	16	6	7	3	3	4	8	11	21	2	8	13	10	6
Ni	-10	-15	-20	-20	-20	-20	-15	-15	-15	-15	4	-20	-20	-20
Cu	31	-10	-10	-10	-10	-10	-10	10	-10	-10	41	22	24	37
Zn	37	36	41	42	46	35	72	58	79	31	19	66	47	-30
Ga	16	11	13	15	17	16	8	17	16	16	14	17	20	15
Ge	1.1	1.2	0.8	1.0	1.0	1.0	1.4	1.1	1.6	1.6	1.3	1.0	0.9	0.8
As	-5	-5	-5	-5	-5	-5	-5	-5	-5	-5	-5	-5	-5	-5
Rb	55	104	63	74	79	79	55	45	41	75	50	58	46	4
Sr	254	183	165	135	152	155	59	282	362	256	243	241	221	145
Y	20.0	26.8	7.4	15.3	13.0	25.5	11.3	23.0	21.4	27.7	15.5	15.6	26.4	28.5
Zr	132	171	147	98	138	148	87	136	132	203	97	89	179	65
Nb	5.9	9.2	2.8	4.4	5.4	6.0	5.4	9.7	7.1	17.7	7.1	4.6	6.4	2.7
Mo	0	-2	-2	-2	-2	-2	-2	-2	-2	5	49	-2	-2	-2
Ag	-0.5	-0.5	-0.5	-0.5	-0.5	-0.5	-0.5	-0.5	-0.5	-0.5	-0.5	-0.5	-0.5	-0.5
In	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1
Sn	0.8	1.5	-1.0	1.0	1.2	1.1	2.0	1.0	-1.0	1.0	-1.0	-1.0	1.8	-1.0
Sb	0.21	0.25	0.21	-0.20	-0.20	0.21	-0.20	-0.20	-0.20	-0.20	0.85	0.89	0.33	0.52
Cs	0.5	1.1	1.0	1.1	1.0	0.9	2.2	0.6	0.3	1.0	0.6	1.3	1.0	0.9
Ba	557	768	1460	1510	1900	835	1030	928	610	1460	529	677	940	266
Hf	3.5	4.6	4.2	3.2	4.0	4.9	2.5	3.2	3.2	5.2	2.7	2.6	5.1	2.6
Ta	0.42	0.75	0.30	0.60	0.63	0.94	0.50	0.70	0.40	1.30	0.55	0.63	0.69	0.31
W	0.3	0.4	-0.5	-0.5	-0.5	-0.5	0.4	-0.2	0.3	-0.2	2.5	1.0	0.8	-0.5
Tl	0.17	0.40	0.24	0.26	0.34	0.30	0.29	0.15	0.21	0.24	0.20	0.21	0.18	-0.05
Pb	-5	7	13	12	17	11	-5	-5	6	5	3	7	9	-5
Bi	-0.05	-0.06	0.12	-0.10	-0.10	0.14	-0.06	-0.06	-0.06	-0.06	0.02	0.27	0.76	0.14
Th	7.46	8.12	3.51	9.46	9.05	11.51	7.01	6.36	3.07	9.47	5.90	7.08	6.74	2.62
U	1.17	1.65	0.72	1.07	1.11	2.52	1.29	1.60	0.93	2.39	1.77	2.00	2.02	0.80
La	15.5	23.8	11.9	25.1	17.6	23.5	17.2	18.6	11.4	37.6	15.5	13.5	19.4	8.8
Ce	30.2	43.6	19.6	42.6	40.2	45.7	30.2	36.2	23.9	70.1	29.4	26.7	39.6	18.8
Pr	3.39	5.03	1.93	4.49	2.97	4.90	3.34	4.00	3.10	7.95	3.37	3.05	4.69	2.38
Nd	13.7	18.8	7.2	15.8	10.5	18.3	12.6	15.0	13.1	28.5	13.0	12.2	19.4	10.7
Sm	2.77	3.76	1.36	2.85	1.99	3.66	2.33	3.20	3.11	5.23	2.67	2.59	4.26	3.00
Eu	0.86	1.01	0.71	0.68	0.81	0.80	0.78	0.97	1.07	1.17	0.76	0.77	1.13	0.96
Gd	3.05	3.91	1.31	2.57	1.96	3.39	2.30	3.18	3.28	4.35	2.41	2.44	3.94	3.26
Tb	0.48	0.72	0.23	0.47	0.36	0.68	0.38	0.61	0.63	0.77	0.43	0.44	0.75	0.74
Dy	2.89	4.35	1.36	2.65	2.16	4.32	2.06	3.62	3.64	4.48	2.55	2.66	4.49	4.82
Ho	0.61	0.89	0.27	0.54	0.46	0.89	0.41	0.75	0.75	0.91	0.53	0.54	0.91	1.04
Er	1.94	2.75	0.85	1.69	1.45	2.89	1.14	2.34	2.25	2.85	1.66	1.71	2.88	3.29
Tm	0.305	0.440	0.123	0.265	0.231	0.471	0.180	0.366	0.334	0.453	0.264	0.257	0.427	0.509
Yb	1.91	3.03	0.90	1.85	1.58	3.24	1.26	2.35	2.21	2.98	1.74	1.88	2.87	3.36
Lu	0.315	0.450	0.148	0.284	0.266	0.496	0.185	0.355	0.320	0.452	0.285	0.289	0.442	0.539
Easthing[3] Northing	461657 6960458	450404 6962447	461850 6957600	437710 6969210	440230 6969650	447950 6962770	512555 6899834	527427 6896357	528634, 6896362	530450 6896473	512637 6896607	503529 6898002	514153 6892490	514331 6889312

Analytical Method: Samples were prepared using a ceramic mill and analyzed for major, trace and rare-earth elements (REE) at Activation Laboratories in Ancaster, Ontario. Major element concentrations were determined by fusion X-ray fluorescence (XRF). Trace elements and REE were analyzed by inductively coupled plasma mass spectrometry (ICP-MS) at research detection limits.

Notes: [1]Samples are located with capital letters in Figures 12 and 16. [2]Unit and rock codes: *Ttlm* = Tatlmain batholith (quartz diorite to granite), *LS* = Little Salmon suite, *pg* = pegmatitic hornblende tonalite, *gd* = granodiorite, *qd* = quartz diorite. [3]UTM Zone 8, NAD27.

An alpine peridotite in the Dawson Range, Yukon-Tanana Terrane: Preliminary results and interpretations

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University of Victoria

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ABSTRACT

This report summarizes the results of geological mapping and preliminary petrological studies of an exposure of ultramafic rocks, the Buffalo Pitts Peridotite (BPP), in the eastern Dawson Range, central Yukon. The BPP is characterized by fresh spinel peridotite. Plagioclase mantles on spinel grains are interpreted to have developed during decompressive metamorphism during exhumation from sub-crustal depths to mid- to upper-crustal depths. The peridotite body forms a foliaform lens 580 m by 100 m that is enclosed in and intruded by leucocratic, biotite-garnet-corundum blue orthogneiss. The peridotite and blue corundum orthogneiss are in turn hosted in a north-dipping panel of amphibolite-grade metamorphic rocks that are included in the pericratonic Devono-Mississippian Wolverine Creek metamorphic suite, part of the Yukon-Tanana Terrane. Quartzite, quartz-mica schist and amphibolite with minor marble and calc-silicate units occur largely south of, and structurally beneath the peridotite body. Leucocratic tonalite gneiss, part of the ~357 Ma Selwyn Gneiss, occurs north of, and structurally above the BPP. Tonalite veins intrude the blue corundum orthogneiss and are interpreted as marginal intrusions of the Selwyn orthogneiss. Intrusion of dykes derived from the Selwyn Gneiss requires exhumation and emplacement of the BPP and the enclosing blue corundum orthogneiss in or prior to the earliest Mississippian.

RÉSUMÉ

Le présent sommaire décrit les résultats de cartographie géologique et d'études pétrographiques préliminaires d'un affleurement de roches ultramafiques, la Péridotite de Buffalo Pitts (PBP), dans l'est du chaînon Dawson, du centre du Yukon. La PBP est caractérisée par une péridotite à spinelle non altérée. L'examen des manteaux de plagioclases sur les grains de spinelle indique qu'ils se sont formés en cours d'un métamorphisme de décompression associé à l'exhumation de la pérodite depuis des profondeurs subcrustales jusqu'à des niveaux moyens à supérieurs de la croute. Le corps de péridotite forme une lentille foliacée de 350 m sur 40 m dans une gangue d'orthogneiss à biotite-grenat-corindon leucocrate bleu intrusif. La péridotite et l'orthogneiss à corindon bleu sont à leur tour logés dans un panneau de roches métamorphiques du faciès des amphibolites, de pendage nord, qui fait partie de la série métamorphique péricratonique de Wolverine Creek, d'âge Dévono-Mississippien, du terrane de Yukon-Tanana. Un quartzite, un schiste à quartz-mica et une amphibolite, ainsi que quelques unités de marbre et silicate calcique, se retrouvent essentiellement au sud et structuralement en-dessous du corps de péridotite. Un gneiss tonalitique leucocrate, faisant partie du gneiss de Selwyn âgé de ~357 Ma, se trouve au nord et structuralement au-dessus de la PBP. Des filons de tonalite qui pénètrent dans l'orthogneiss à corindon bleu sont considérés commes des intrusions marginales de l'orthogneiss de Selwyn. Cette relation suppose que la PBP et sa gangue d'orthogneiss à corindon bleu ont été exhumées et mises en place pendant ou avant le Mississippien précoce.

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INTRODUCTION

This paper reports on the preliminary results of 1:5000-scale geological mapping of a peridotite body and its wall rocks within the Dawson Range, central Yukon (115I/12; Fig. 1), conducted during the summer of 2000.

The ultramafic body, hereafter referred to as the Buffalo Pitts Peridotite (BPP), occurs within subdued topography in a saddle between hilltops. It forms an elongate, east-trending lens and is hosted within a distinctive, blue, corundum-bearing orthogneiss. Exposures consist of low relief surfaces that were stripped of vegetation during a 1995 forest fire, and outcrops occur atop small local rises in elevation.

Previous work in the area includes reconnaissance mapping by Cairnes (1916); local 1:15 000-scale mapping by Bostock (1936) and Johnston (1963); 1:250 000-scale mapping by Tempelman-Kluit (1984); and 1:50 000-scale mapping by Johnston and Hachey (1993a). Johnston (1995) published a 1:100 000-scale geologic compilation map of the Dawson Range. Johnston and Hachey (1993a,b) first documented the existence of the BPP; however, they interpreted the ultramafic body as an intrusion.

Situated between the Minto-Battle Fault to the south (formerly the Hootchekoo fault, Johnston, 1999) and the Yukon River to the north, the study area is underlain by predominantly Devono-Mississippian rocks of the

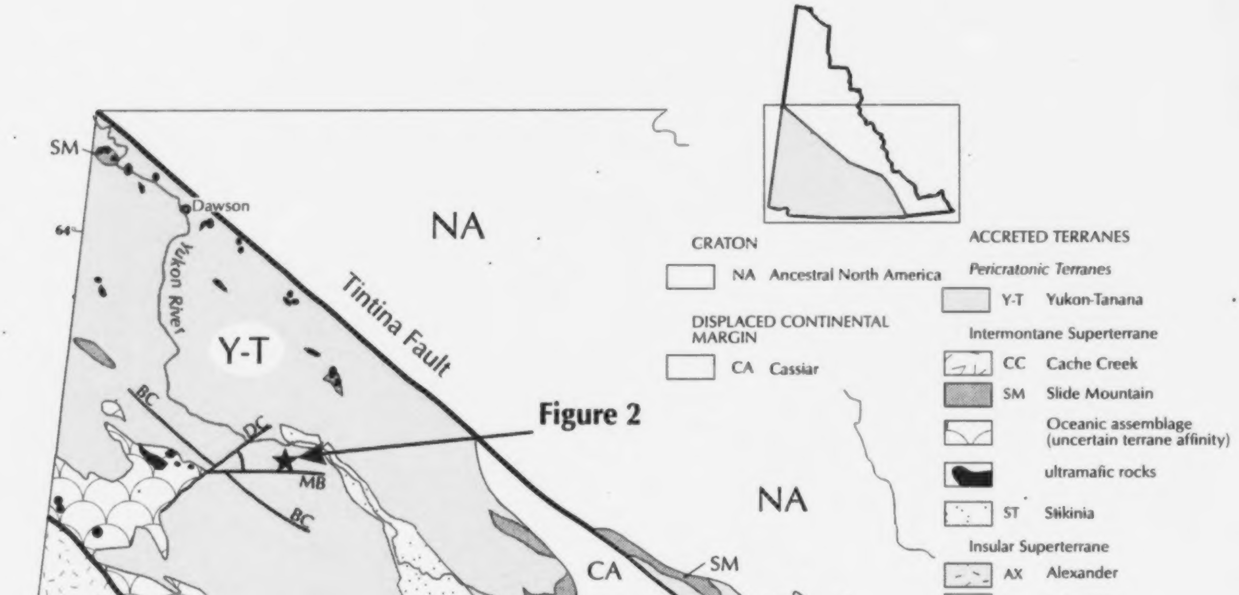
SM
Dawson
64°
Yukon River
NA
Tintina Fault
Y-T
BC
DC
Figure 2
MB
BC
NA
CA
SM
WR
ST
SM
Y-T
Y-T
Denali Fault
Y-T
CA
SM
WR
AX
Whitehorse
SM
CA
CG
141°
WR
60°
CC
Y-T
0
100
km
CRATON
NA Ancestral North America
DISPLACED CONTINENTAL MARGIN
CA Cassiar
ACCRETED TERRANES
Pericratonic Terranes
Y-T Yukon-Tanana
Intermontane Superterrane
CC Cache Creek
SM Slide Mountain
Oceanic assemblage (uncertain terrane affinity)
ultramafic rocks
ST Stikinia
Insular Superterrane
AX Alexander
WR Wrangellia
Outer Terranes
CG Chugach

Figure 1. *Terrane map of southwestern Yukon modified from Wheeler and McFeely (1991). Ultramafic rocks indicated in black. The star marks the Buffalo Pitts Peridotite. Accreted terranes are shown in grey on a location map at upper right. Faults include the Dip Creek (DC), Big Creek (BC) and Minto-Battle (MB; after Johnston, 1999).*

Wolverine Creek metamorphic suite (Fig. 2a), part of the Yukon-Tanana Terrane. This assemblage dips regionally to the north and consists of an undifferentiated quartzite and quartz mica-schist unit, and a structurally overlying amphibolite unit. These two units locally include minor amounts of marble and calc-silicate rock, and are structurally overlain to the north by leucocratic orthogneiss, thought to be part of the Selwyn orthogneiss. The Selwyn orthogneiss forms an elongate (> 100 km long) northwest-trending body that has been interpreted as being allochthonous relative to the underlying amphibolite and quartz-mica schist (Wheeler and McFeeley, 1991). The BPP and the spatially associated corundum-bearing orthogneiss occur along the contact between the Selwyn orthogneiss and the underlying amphibolite and quartz-mica schist units. Local occurrences of gabbro and a garnetiferous greenstone are also present within this contact zone.

The following is a description of the rock units that constitute the BPP and its wall rocks, and an explanation of the relations between these units. These data are consistent with emplacement of the BPP as an alpine peridotite prior to intrusion by the plutonic protolith of the Selwyn Gneiss, and points to significant Paleozoic tectonism in the Yukon-Tanana Terrane; however much work remains to be done to confirm this interpretation.

UNIT DESCRIPTIONS

QUARTZITE / QUARTZ-MICA SCHIST

This unit consists largely of fine- to medium-grained micaceous quartzite, and subordinate quartz-mica schist, marble and calc-silicate. Quartzite is black to tan, weathers brown, orange or grey, and consists of 90% translucent quartz grains. Colour banding is common, consisting of alternating black and tan brown bands 1 to 3 cm wide, and is thought to represent primary compositional layering (Johnston and Hachey, 1993b). The black colour is thought to result from the presence of graphite. Small amounts (1 to 10 %) of fine-grained biotite, muscovite and feldspar are commonly present. Foliaform lenses of milky white quartz ranging from 1 cm to 3 m in length are common.

Buff- to brown-weathering, grey, medium- to coarse-grained, quartzofeldspathic muscovite-biotite schist occurs as layers one to tens of metres thick. The rock consists of up to 50% mica with lesser amounts of quartz and feldspar. White, medium- to coarse-grained marble occurs in the southeastern corner of the study area. The weathered surface is orange and the rock consists of 90% calcite. Other mineral constituents include quartz, feldspar, phlogopite, diopside, epidote, and garnet. Pale-green-weathering, white to green, garnet-diopside-epidote calc-silicate rock, with minor calcite occurs as lenses within marble and as isolated lenses enclosed in micaceous quartzite.

The quartzite unit is inferred to be metamorphosed clastic rocks. This is consistent with the quartzose nature of the unit, and the presence of metapelitic rocks. The quartzite and quartz-mica schist unit is intruded by blue, corundum-bearing orthogneiss, which in turn hosts rare xenoliths of quartzite.

AMPHIBOLITE

Green- to brown-weathering, black to dark green, medium- to coarse-grained amphibolite occurs as continuous and discontinuous horizons, one centimetre to tens of metres thick. Garnet and diopside are locally present. Additional components include biotite, feldspar, quartz, titanite and epidote. Chloritic alteration of hornblende and biotite is common, as is sericitic alteration of feldspar. Amphibolite occurs along contacts between orthogneiss and quartzite (Johnston and Hachey, 1993a,b). A hilltop outcrop 700 m west of the BPP constitutes a layer of amphibolite that is enclosed by quartzite. This amphibolite layer is along strike from, and is thought to be continuous with, a westward thickening layer of amphibolite found to the west of the study area which is thought to separate the quartzite and quartz-mica schist from the more northerly Selwyn orthogneiss. Amphibolite may represent metamorphosed mafic flows and dykes either the same age as, or younger than, the quartzite (Johnston and Hachey, 1993b).

SELWYN ORTHOGNEISS

Grey-weathering, grey, medium- to coarse-grained, leucocratic, equigranular hornblende-biotite quartz diorite to granodiorite gneiss is the structurally shallowest unit, and underlies the northern part of the study area. Mafic minerals commonly comprise less than 5% of the rock. Hornblende is the dominant mafic mineral. Significant amounts of biotite are locally present, imparting a schistose texture to the rock. Feldspars occur as milky white subhedral grains. Streaky grey quartz occurs interstitial to other grains.

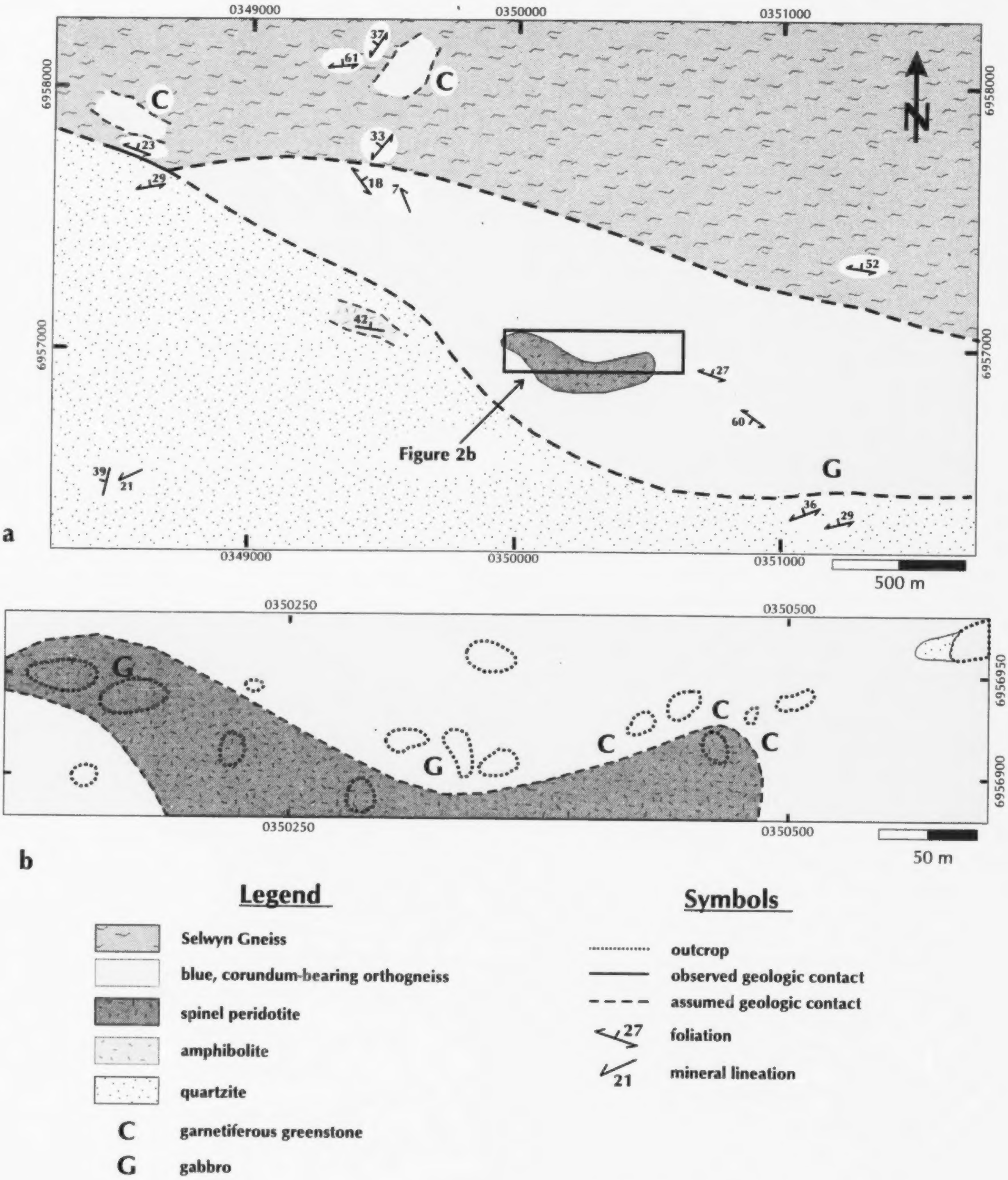
0349000
0350000
0351000
6958000
6957000
C
C
37
61
23
33
29
18
7
42
52
27
60
Figure 2b
G
39
21
36
29
N
a
500 m
0350250
0350500
6956950
6956900
G
G
C
C
C
b
50 m
Legend
Selwyn Gneiss
blue, corundum-bearing orthogneiss
spinel peridotite
amphibolite
quartzite
C garnetiferous greenstone
G gabbro
Symbols
outcrop
observed geologic contact
assumed geologic contact
27 foliation
21 mineral lineation

Figure 2. Geology of the study area, the location of which is indicated in Figure 1. The Minto-Battle fault lies 1.5 km south of the study area; (a) shows the relation of the BPP to its wall rocks; (b) detailed geology of the BPP.

The homogeneity and lithology of the gneiss is consistent with interpretation as an orthogneiss derived from an intrusion. Dykes intrude and post-date the corundum-bearing orthogneiss. A U-Pb zircon age determination of 355.4 +13.7 / -6.1 Ma for a sample of the Selwyn Gneiss collected northwest of the study area has been interpreted as the age of crystallization of the igneous protolith of the orthogneiss (Mortensen, 1986, 1992). A sample of orthogneiss thought to be correlative with the Selwyn orthogneiss from south of the study area (Johnston and Hachey, 1993b) yielded a similar U-Pb zircon age of 357.9 ± 3.5 Ma (S. Johnston and J. Mortensen, pers. comm., 1994; Johnston and Shives, 1995).

CORUNDUM-BEARING ORTHOGNEISS

A blue- to orange- to brown-weathering, blue-grey, fine- to medium-grained, leucocratic, granitic orthogneiss occurs between the Selwyn Gneiss to the north and the quartzite to the south. Isolated outcrops occur over an area 3.5 km long by 1.1 km wide, mostly in the immediate vicinity of the BPP (Fig. 2). The rock consists largely of potassium feldspar (45%), quartz (25%) and plagioclase feldspar (20%), with lesser amounts of biotite and muscovite (>2%). The presence of minor amounts of corundum (≤ 1%) imparts a remarkable blue colour to this rock. Anhedral to subhedral microcline is the dominant potash feldspar and ranges from 0.5 to 2.5 mm long, and is characterized by tartan twinning, microperthitic texture and quartz inclusions. Less abundant, 0.5- to 2.0-mm-long, anhedral to subhedral orthoclase grains with common quartz inclusions are locally present. Anhedral to subhedral plagioclase grains, 0.2 to 3 mm long, exhibit albite and Carlsbad twinning. Myrmekitic texture is common along grain boundaries with microcline and quartz. Quartz, and to a lesser extent plagioclase, exhibit a bimodal grain-size distribution, with fine-grained mosaic quartz and plagioclase forming an equigranular groundmass that forms 25% of the rock, and larger grains forming continuous bands that define a foliation (Fig. 3). Quartz grains in the groundmass consist of 5- and 6-sided grains that commonly intersect at 120° and define a polygonal, granoblastic texture (Fig. 3). Foliaform anhedral to subhedral quartz porphyroblasts range from 0.5 to 2 mm in length, and exhibit undulose extinction and sutured grain boundaries.

The groundmass includes minor amounts of muscovite, biotite, garnet, and corundum. Brown to red-brown, subhedral to euhedral biotite grains range in length from 0.3 to 1.5 mm. Colourless, subhedral to euhedral muscovite grains range from 0.1 to 0.5 mm in length and commonly grow across and at the expense of biotite. Large mica grains are commonly kinked and deformed. Irregular relic garnet grains occur within micaceous clots. Garnet is overgrown and is interpreted as being replaced by biotite grains.

Corundum occurs as blue, subhedral to euhedral blebs 0.05 to 0.3 mm long and up to 1 mm in diameter. The blue colour of some corundum is commonly attributable to trace amounts of Fe^{2+} and Ti^{4+} (Nesse, 1991; Klein and

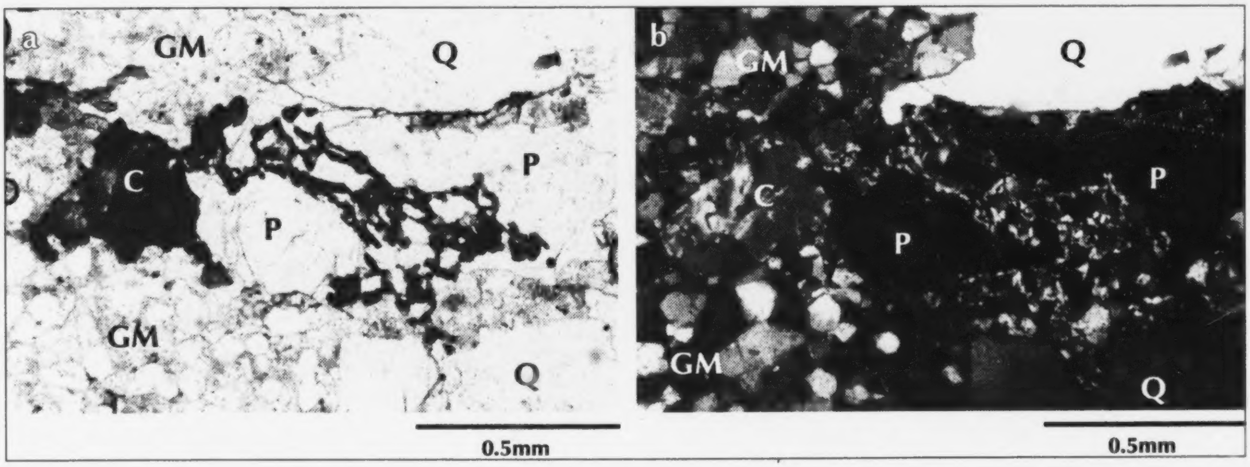

Figure 3. *Photomicrographs of blue corundum-bearing orthogneiss, (a) in plane-polarized light and (b) with crossed nicols. Quartz (Q) and plagioclase (P) megacrysts are surrounded in a predominantly quartz groundmass (GM) in which grains of corundum (C) are apparent.*

Hurlbut, 1993). The corundum appears to be developed, at least in part, at the expense of plagioclase. Rare optically continuous, relic megacrysts of plagioclase are divisible into domains separated by finely crystalline, corundum-bearing groundmass (Fig. 3). Minor retrogressive alteration of the blue orthogneiss is common. Sericite after feldspar and biotite is common, while chlorite after biotite is less common.

Garnetiferous greenstone weathers green to dun-brown, is grey-black to black, has grain sizes ranging from 0.2 to 1.5 mm in diameter, and locally consists of 50% disseminated garnet grains. Massive garnet is locally developed. Garnetiferous greenstone is intimately associated with blue corundum orthogneiss and is ubiquitous near the eastern end of the peridotite body.

Blue corundum orthogneiss intrudes quartzite, amphibolite and peridotite. Garnetiferous greenstone, thought to be the product of metasomatism and contact metamorphism of the peridotite body, is commonly developed along the margins of the blue corundum orthogneiss, and also occurs as 10- to 100-cm-long boudins and inclusions within a mortar of blue corundum orthogneiss (Fig. 4).

The blue corundum orthogneiss, together with the garnetiferous greenstone, is folded, and is locally strongly foliated to gneissic. The gneissosity consists of alternating colour intensity between normal pale grey blue, and bright blue. Dykes of leucocratic orthogneiss intrude the folded and foliated blue corundum orthogneiss. Dykes consist of 5- to 10-cm-wide grey-weathering, grey, medium- to coarse-grained, leucocratic tonalitic veins and are lithologically similar to the leucocratic tonalite gneiss that forms the bulk of the Selwyn Gneiss. These rocks contain quartz and plagioclase, with minor to trace amounts of hornblende and mica. The dykes increase in size and volume northward toward the main body of the Selwyn Gneiss. Based on their lithology and spatial association with the Selwyn Gneiss, they are interpreted as marginal intrusions of the Selwyn Gneiss.

These contact relations suggest that the blue corundum-bearing orthogneiss post-dates rocks of the Wolverine Creek metamorphic suite. If the tonalitic dykes that intrude the blue corundum orthogneiss are marginal intrusions of the Selwyn Gneiss, then the corundum-bearing orthogneiss is older than about 357 Ma, the age of the Selwyn Gneiss and correlative orthogneiss mapped to the south (Mortensen, 1986; Johnston and Shives, 1995). However, the fact that the region includes Devonian, Mississippian, Permian, Jurassic and Cretaceous granitoids requires that further work be done to verify the source of these dykes.

SPINEL PERIDOTITE

The Buffalo Pitts Peridotite outcrops near the centre of the study area forming an east-trending exposure that is 580 m long and 100 m wide. It is surrounded on all sides by blue, corundum-bearing orthogneiss (Fig. 2). Peridotite is a dun-brown-weathering, dark green to black spinel lherzolite composed of olivine (50%), orthopyroxene (25%) and clinopyroxene (< 20%). The rock is commonly fresh (Figs. 5, 6).

Rust-brown-weathering, deep green to black, anhedral to euhedral olivine range from 0.4 to 2.5 mm in diameter. Partially serpentinized grains are blue-black on a fresh

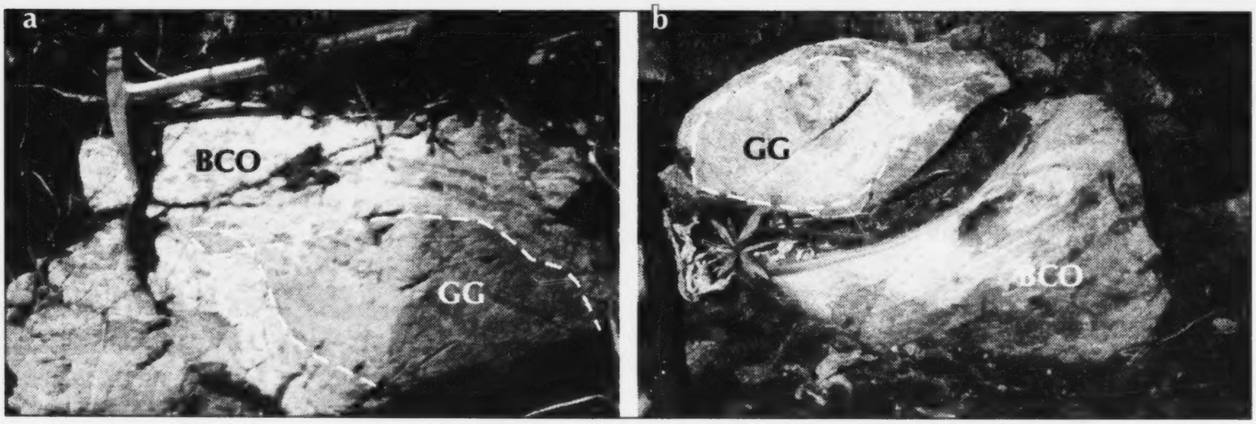

Figure 4. *(a) Garnetiferous greenstone (GG) boudin within blue corundum orthogneiss (BCO). Rock hammer is 40 cm long. (b) 12-cm-long ovoid garnetiferous greenstone (outlined by dashed line) within blue corundum orthogneiss.*

surface. Iddingsite alteration along irregular fractures is locally developed. Beige-weathering, deep green, anhedral to subhedral orthopyroxene range from 0.3 to 2.5 mm. Rare unidentified inclusions are locally present along cleavage planes. Grey-black weathering, ruby red spinel is commonly mantled by thin (< 0.5 mm), white rims thought to consist largely of plagioclase (P. Erdmer, written communication, 1993; Fig. 5). Spinel grains are typically 2 to 5 mm in diameter, being larger and more abundant in the more easterly outcrops. Rare, emerald green, fresh, anhedral to euhedral chromium diopside grains are 0.25 to 2.5 mm in diameter.

A weak, planar fabric is present and is defined by 3- to 40-mm mafic bands and <3-mm layers of spinel, plagioclase, opaques and groundmass (Fig. 6). Serpentinization is minor (< 5%). Serpentine and talc occur as thin veinlets and as rare, blue and white, veins that commonly crosscut layering at high angles. Accessory minerals include magnetite (along the margins of serpentinized olivine grains), chlorite, plagioclase and ilmenite. Alteration products include talc, serpentine and magnetite after olivine and pyroxenes, iddingsite after olivine, and uralite after pyroxenes.

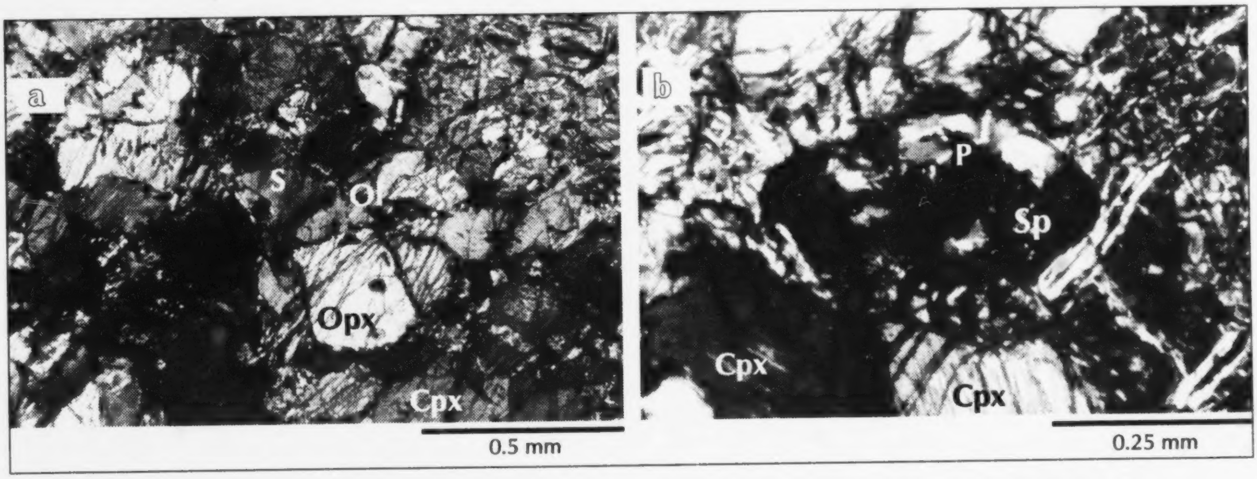

Figure 5. *Photomicrographs with crossed nicols of spinel lherzolite. (a) Orthopyroxene (Opx), olivine (Ol) and clinopyroxene (Cpx). Olivine grain at centre is partially altered to serpentine (S). (b) Spinel (Sp) grain with partial plagioclase (P) halo.*

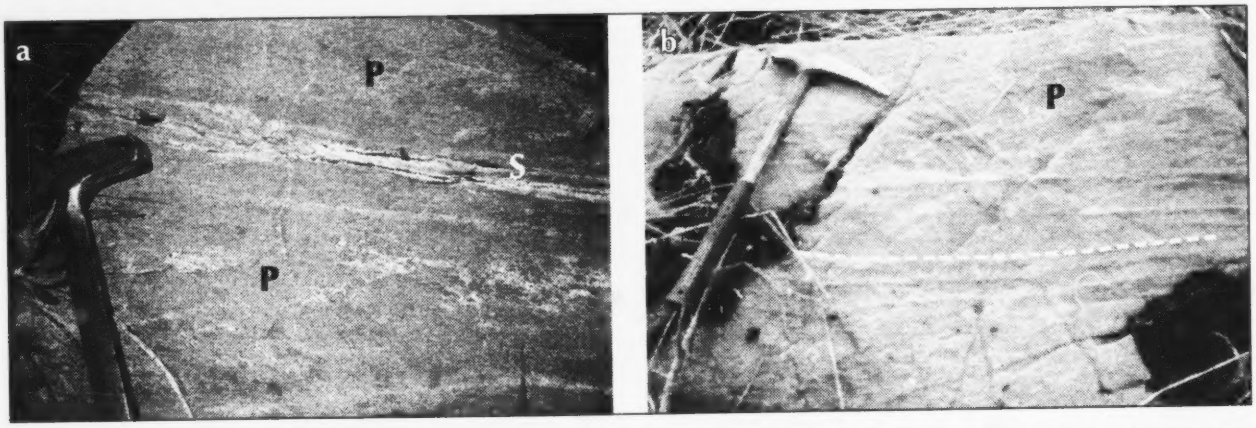

Figure 6. *Weak planar-fabric development in peridotite (P). (a) Rare white to blue-white, 1- to 2-cm-thick serpentine (S) veins parallel fabric. (b) Subtle planar fabric within peridotite. One band is highlighted by dashed line. Rock hammer for scale.*

A 1-m-wide lens of coarse crystalline, strongly sheared to locally gneissic, gabbro was found near the western extent of the BPP. The rock contains chalky white plagioclase and grey to green pyroxenes, 3 to 5 mm long. To the southeast of the BPP, a second occurrence of gabbro exists as an isolated lens.

Corundum-bearing orthogneiss locally intrudes peridotite, suggesting that the BPP pre-dates the intrusion of the corundum-bearing orthogneiss.

STRUCTURE AND METAMORPHISM

All the units described here share the regionally developed, northwest-trending, northeast-dipping fabric (Fig.2; schistosity and compositional layering in the quartzite and quartz-mica schist; layering and mineral alignment in the amphibolite; gneissosity and foliation in the Selwyn Gneiss and the blue corundum gneiss). Weak fabric development in the peridotite is interpreted to have developed at this time, and is thought to be poorly developed due to the rheological contrast between the peridotite and its wall rocks. Rare intrafolial folds, and folds of an older foliation with axial planes parallel to the regional foliation (observed in quartzite, amphibolite and blue corundum orthogneiss), indicate that the regional fabric (S_2) developed in response to folding and transposition of an older foliation (S_1). Regional fabric development was synchronous with metamorphism, indicated by the development of foliation-parallel muscovite and biotite in the quartz-mica schist, and hornblende in the amphibolite, consistent with syn-kinematic amphibolite facies metamorphism.

Plagioclase halos developed on spinel grains in the peridotite are consistent with syn-kinematic decompressive metamorphism, with spinel breaking down to plagioclase during exhumation from sub-crustal depths, to mid- to upper-crustal levels.

Skeletal corundum ± garnet ± biotite in the corundum orthogneiss is thought to predate regional metamorphism, as these grains are overgrown by muscovite. Therefore, high-temperature metamorphism recorded in the blue corundum orthogneiss is thought to predate the regional S_2 fabric.

CONCLUSIONS

Our data are consistent with interpretation of the Buffalo Pitts Peridotite (BPP) as an alpine peridotite emplaced during the latest Devonian. The important observations are as follows:

1. The lack of zoning within the peridotite body, its mineralogy, and the evidence for decompressive metamorphism during exhumation from mantle depths indicate that the BPP is tectonically emplaced and constitutes an Alpine-type peridotite (cf. Hall, 1996; Mezger, 2000).
2. The peridotite is spatially associated with, and appears to be largely hosted within, an intrusive body. High-temperature metamorphism of this intrusive body resulted in the recrystallization of igneous minerals and the development of corundum ± garnet ± biotite.
3. The peridotite body and the blue corundum orthogneiss predate, and are intruded by, tonalitic dykes, which may be marginal intrusions of the Selwyn Gneiss. If so, this would restrict the age of emplacement of the peridotite to pre-357 Ma, which is the age of the Selwyn orthogneiss.
4. Subsequent regional deformation and syn-kinematic, amphibolite-facies metamorphism post-dated emplacement of the peridotite and intrusion by the Selwyn Gneiss.

A number of questions remain to be answered. For instance:

1. What is the nature of the relation between the blue corundum orthogneiss and the peridotite? The peridotite body appears to be entirely housed within the intrusive blue corundum orthogneiss, a rock which has not been previously documented anywhere in the Yukon-Tanana Terrane. It seems likely that emplacement and preservation of the BPP is related to this intrusive body, however, the nature of that relation remains a matter of conjecture.
2. What is the relation between regional syn-kinematic amphibolite facies metamorphism and the presence of metamorphic corundum in the blue orthogneiss? High temperatures, significantly in excess of those required to produce the regional metamorphic mineral paragenesis, are required to produce the metamorphic corundum. How this high temperature event relates to emplacement of the BPP, and to the regional metamorphism and deformation, remains to be resolved.

3. Are the tonalite dykes that intrude the blue corundum orthogneiss related to the Selwyn Gneiss? This important relation needs to be confirmed, as interpretation of the peridotite being emplaced prior to about 357 Ma is based entirely on this correlation.
4. What is the tectonic significance of the BPP? Recent studies (see results of ongoing Ancient Pacific Margin NATMAP project, Colpron and Yukon-Tanana Terrane Working Group, this volume) have demonstrated that Yukon-Tanana Terrane is characterized by a significant regional Early Mississippian tectono-magmatic event. Is emplacement of the BPP somehow related to the Early Mississippian orogenesis?

Toward addressing these questions, comprehensive petrological, geochronological and geochemical studies of the BPP and its wall rocks are being pursued. In addition to addressing these questions, these studies will provide an improved understanding of the processes responsible for the emplacement and preservation of mantle rocks within the upper crust.

ACKNOWLEDGEMENTS

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Preliminary geology of the southeastern part of Ddhaw Ghro Special Management Area

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Contributions from Danièle Héon

Fonseca, A., 2001. Preliminary geology of the southeastern part of Ddhaw Ghro Special Management Area. *In*: Yukon Exploration and Geology 2000, D.S. Emond and L.H. Weston (eds.), Exploration and Geological Services Division, Yukon, Indian and Northern Affairs Canada, p. 147-153.

ABSTRACT

Ddhaw Ghro Special Management Area (SMA) is currently withdrawn from mineral claim disposition. A mineral resource assessment of Ddhaw Ghro SMA will be carried out during the fall, 2001, in support of finalizing its management plan. Mapping at 1:20 000 scale, sampling, and prospecting in southeastern Ddhaw Ghro SMA shows complex structural and stratigraphic relations in layered rocks, which are further complicated by intense contact metamorphic alteration around McArthur Batholith. Rocks in roof pendants in the McArthur Batholith are pervasively altered. Southeast of the batholith, a structurally imbricated sequence of Ordovician (Duo Lake Formation) through Devonian (Portrait Lake Formation) rocks contain a slice of maroon and green shale, which may represent a far travelled thrust sheet of Early Cambrian Narchilla Formation, or a facies change in upper Road River Group towards Nogold Unit type lithologies.

Sulphide minerals are common in strongly oxidized areas in the contact metamorphic aureole, and in more localized skarn-altered zones.

RÉSUMÉ

La région de gestion spéciale (RGS) de Ddhaw Ghro est actuellement soustraite de toute disposition de claims miniers. On évaluera au cours de l'automne 2001 les ressources minérales de la RGS de Ddhaw Ghro dans le but d'en compléter le plan de gestion. Selon les travaux de cartographie au 1/20 000, d'échantillonnage et de prospection menés dans le sud-est de la RGS de Ddhaw Ghro, il existe dans les roches litées des relations structurales et stratigraphiques complexes, qui sont d'autant plus compliquées à cause de l'intense altération métamorphique de contact autour du batholithe de McArthur. Les roches encaissantes qui se retrouvent dans des enclaves dans le batholithe sont fortement altérées. Au sud-est du batholithe, une séquence à structure imbriquée de roches datant de l'Ordovicien (Formation de Duo Lake) au Dévonien (Formation de Portrait Lake) renferme une couche de shale vert et marron. Il pourrait s'agir d'une nappe, charriée sur une grande distance, de la Formation de Narchilla du Cambrien précoce ou d'un passage de faciès vers des lithologies du type de l'Unité Nogold dans la partie supérieure du Groupe de Road River.

Les minéraux sulfurés abondent dans les zones fortement oxydées dans l'auréole de contact métamorphique et dans des zones skarnifiées plus localisées.

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INTRODUCTION AND LAND STATUS

McArthur Wildlife Preserve was established in 1972, when an Ecological Reserve notation (#10-21) was applied to the Yukon Territorial Resource Base Maps. Initially, regulations limited hunting activity only, and the map notation flagged the area as having wildlife values. The McArthur Wildlife Preserve was selected as Ddhaw Ghro Special Management Area (SMA) through finalization of the Na'Cho N'yak Dun Final Agreement and negotiations of Selkirk First Nation Land Claims. The Special Management Area was established as a Habitat Protection Area. In 1997, Ddhaw Ghro was withdrawn from land disposition through 2005, or through the completion of a management plan.

PURPOSE AND SCOPE OF WORK

The purpose of this work was to begin the inventory of mineral resources that is needed to conduct a mineral assessment of the area. The mineral assessment will provide information on metallic mineral values of the SMA to the Ddhaw Ghro SMA Working Group (Yukon Government) and Steering Committee (Yukon Government and First Nations), in support of finalizing the management plan as outlined in Chapter 10, Section 6.4.12 of the Selkirk First Nation Final Agreement.

During the summer, 2000, the authors spent six days in the area between Grey Hunter Creek and Sideslip Creek, in the southeastern portion of Ddhaw Ghro SMA. The purpose of this fieldwork was to examine part of the stratigraphy, document known mineral occurrences and investigate the source of geochemical anomalies. Work included 1:20 000-scale mapping, prospecting, geochemical sampling, fossil dating, and petrographic studies. Traverses were based from two fly camps. The first camp was located near the Sideslip mineral occurrence (105M 039, Yukon MINFILE, 1997) and was set to investigate possible mineralized areas within the McArthur Batholith and its associated roof pendant rocks. The second camp was set near Grey Hunter Peak, to investigate the source of anomalous stream geochemical samples (Regional Geochemical Survey (RGS), Hornebrook and Friske, 1988).

LOCATION, ACCESS AND PHYSIOGRAPHY

Ddhaw Ghro Special Management Area consists of 1610 km^2 in central Yukon, located east of the Klondike Highway (Fig. 1). The SMA occupies the southwestern portion of Mayo map sheet (105M), southeastern corner of McQuesten map sheet (115P), and northeastern corner of Glenlyon map sheet (105L). The northwestern corner of Dhaw Ghro SMA is adjacent to the Klondike Highway, and approximately 25 km south of Stewart Crossing. Access to the southeastern portion of the SMA is by helicopter from Mayo (approximately 75 km).

Ddhaw Ghro SMA roughly outlines the high ridges of McArthur Range, immediately northeast of Tintina Trench. Elevations range from 700 m in the northwest corner of the SMA, where forest cover is dense, to areas above 1980 m, characterized by sub-alpine and alpine environments.

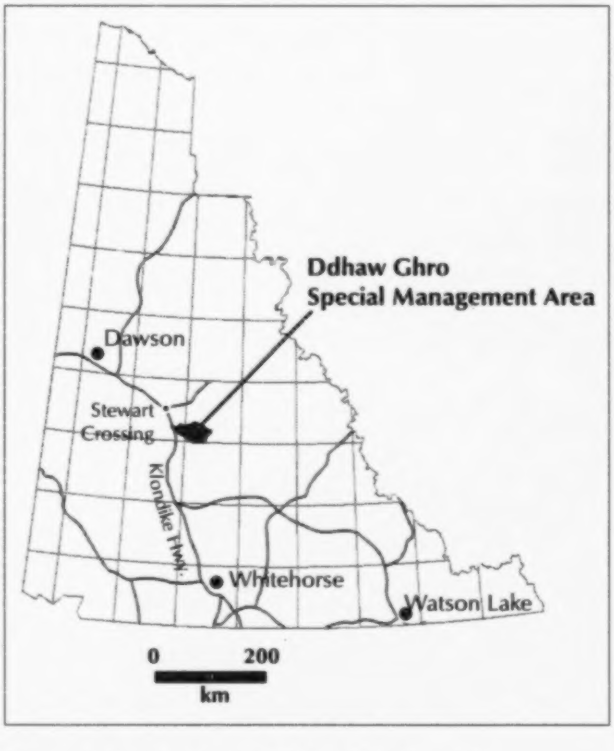


Figure 1. Location map of Ddaw Ghro Special Management Area.

MINERAL EXPLORATION HISTORY

Mineral exploration in the southwestern Mayo map sheet dates as far back as 1929, when Treadwell Yukon Corporation Ltd.'s prospecting party reported discovering the 'Lost Wernecke Copper' (105M 043, Yukon MINFILE, 1997), a large tonnage, low-grade copper deposit in the McArthur Mountains. Treadwell Yukon did not stake the area, and subsequent efforts to locate the copper showings were unsuccessful, despite regional exploration programs by Atlas Exploration Ltd. in 1969 and by United Keno Hill Mines Ltd. in 1970.

Other exploration activity in the area lead to the discovery of the following mineral occurrences: Sideslip (105M 039, Yukon MINFILE, 1997), staked as early as 1950, but certainly in 1969 by Atlas Exploration Ltd.; Great Horn (105M 040, Yukon MINFILE, 1997), staked in 1971 by Great Horn Mg Syndicate Inc.; Ram (105M 041, Yukon MINFILE, 1997), staked in 1966 by Kerr Addison Mines Ltd.; Hotspring (105M 042, Yukon MINFILE, 1997), staked in 1966 by H. Mauthner; and Friesen (105M 051, Yukon MINFILE, 1997), discovered in 1970 by United Keno Hill Mines Ltd., and staked in 1972 by E. Woolven and E. Friesen, and again in 1974 by G. Van Bibber. In 1997, Viceroy Resources Ltd. conducted a regional exploration program in the McArthur Wildlife Preserve, and identified targets for more advanced exploration. Withdrawal of the SMA land from disposition late in the 1997 field season terminated Viceroy's exploration program.

GEOLOGICAL SETTING OF DDHAW GHRO SMA

Roots (1997) mapped the Mayo map sheet (105M) at 1:100 000 scale, and compiled the maps at 1:250 000 scale. Gordey and Makepeace (1999) produced a digital compilation of the geology of the Yukon, from which geology of Ddhaw Ghro SMA is shown in Figure 2.

Ddhaw Ghro SMA is located in western Selwyn Basin, near the Tintina Fault. From Late Proterozoic through Siluro-Devonian time, easterly derived sediments were deposited in Selwyn Basin, a topographic low to the west of the ancient North American margin. In mid-Paleozoic time, Nogold Basin formed along a southeast-trending axis, on what is now the northern part of Ddhaw Ghro SMA. Hyland Group and younger rocks were reworked and their sediments redeposited mainly as grits and maroon and green shale in Nogold Basin (Roots, 1997). Visually, Nogold Unit and Hyland Group are identical,

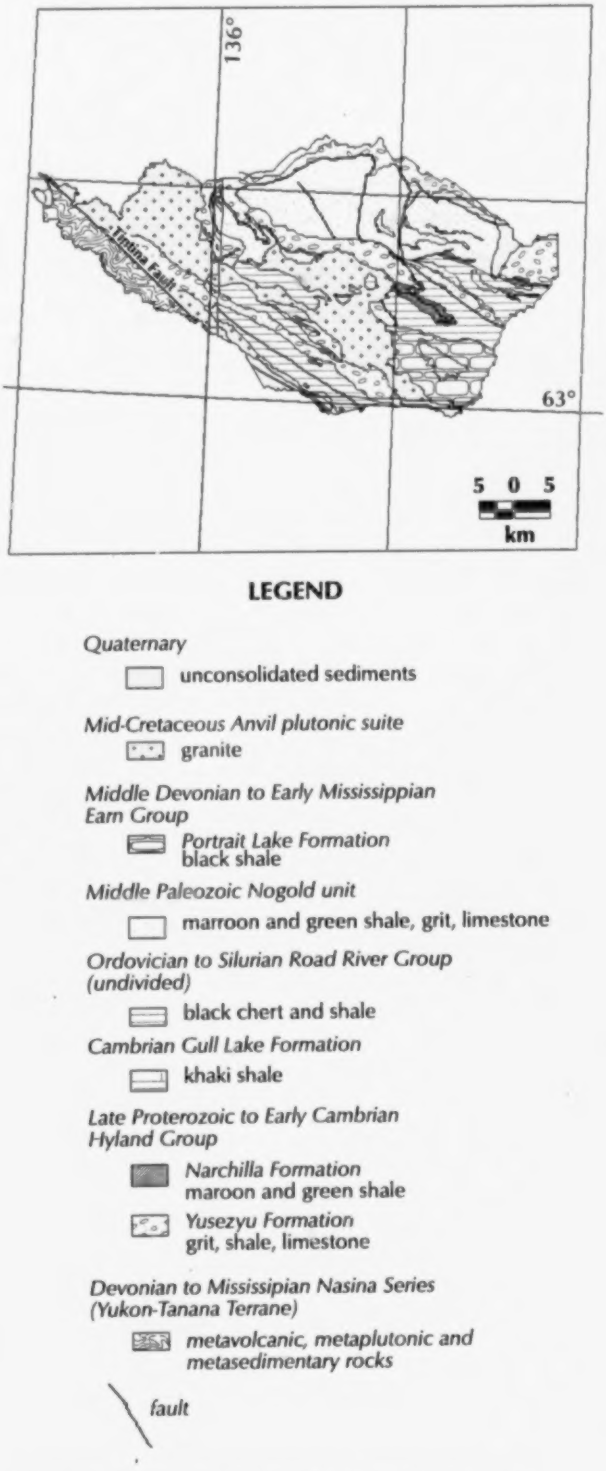
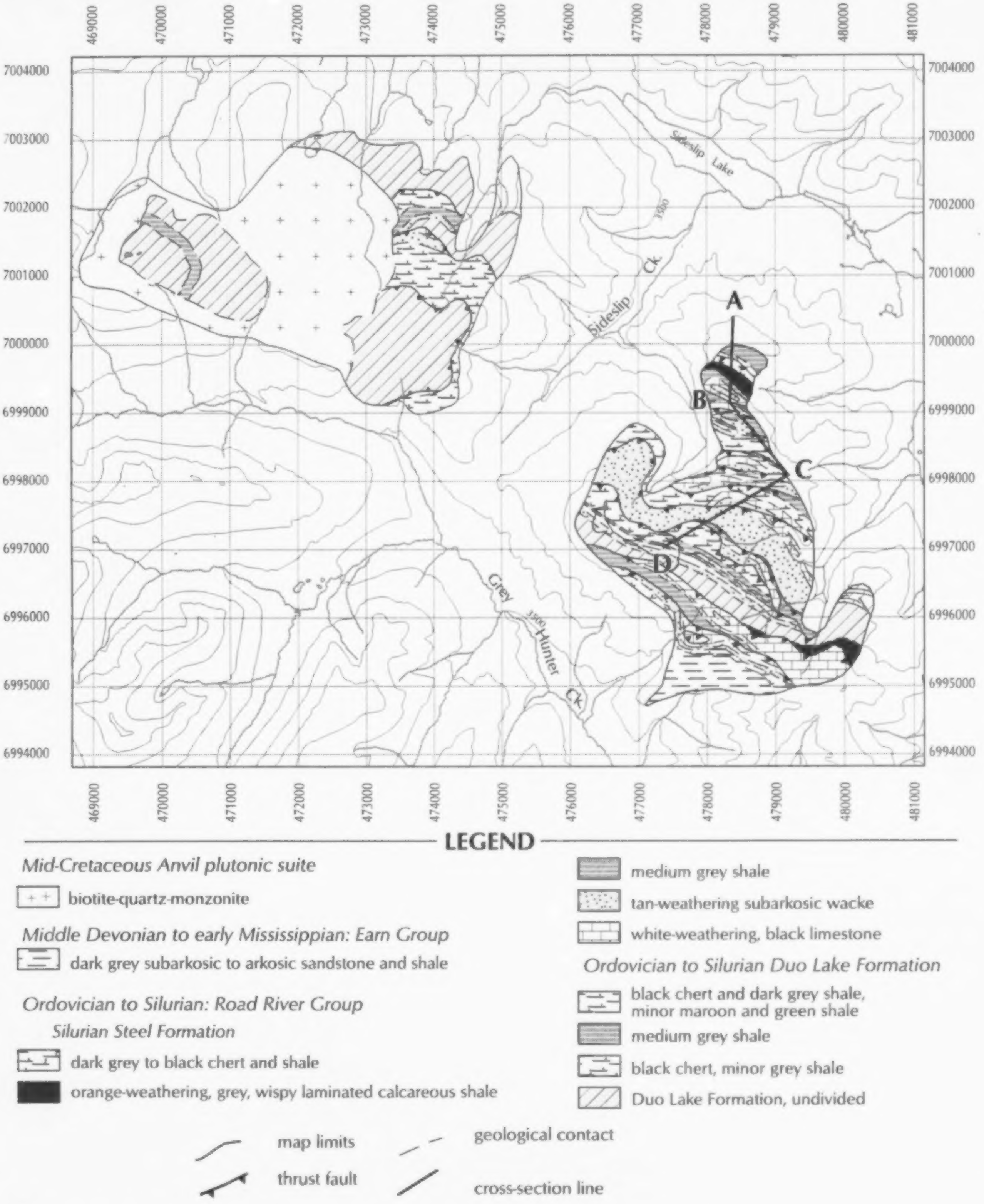

136°
Tintina Fault
63°
5 0 5
km
LEGEND
Quaternary
unconsolidated sediments
Mid-Cretaceous Anvil plutonic suite
granite
Middle Devonian to Early Mississippian Earn Group
Portrait Lake Formation black shale
Middle Paleozoic Nogold unit
marroon and green shale, grit, limestone
Ordovician to Silurian Road River Group (undivided)
black chert and shale
Cambrian Gull Lake Formation
khaki shale
Late Proterozoic to Early Cambrian Hyland Group
Narchilla Formation maroon and green shale
Yusezyu Formation grit, shale, limestone
Devonian to Mississipian Nasina Series (Yukon-Tanana Terrane)
metavolcanic, metaplutonic and metasedimentary rocks
fault

Figure 2. *Regional geology of Ddhaw Ghro Special Management Area (modified from Gordey and Makepeace, 1999).*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6997000
6996000
6995000
6994000
Sideslip Lake
Sideslip Ck.
3500
A
B
C
D
Grey Hunter Ck.
LEGEND
Mid-Cretaceous Anvil plutonic suite
biotite-quartz-monzonite
Middle Devonian to early Mississippian: Earn Group
dark grey subarkosic to arkosic sandstone and shale
Ordovician to Silurian: Road River Group
Silurian Steel Formation
dark grey to black chert and shale
orange-weathering, grey, wispy laminated calcareous shale
medium grey shale
tan-weathering subarkosic wacke
white-weathering, black limestone
Ordovician to Silurian Duo Lake Formation
black chert and dark grey shale, minor maroon and green shale
medium grey shale
black chert, minor grey shale
Duo Lake Formation, undivided
map limits
geological contact
thrust fault
cross-section line

Figure 3. *Geological map of southeastern Ddhaw Ghro.*

and the distinction is made based on fossil ages. In Devonian time, westerly and northwesterly derived Earn Group dark turbidites and minor chert deposited upon Selwyn Basin strata (Gordey, 1992).

Mesozoic deformation produced southeast-trending, southeast-plunging folds, and northeast-verging thrusts in the southern part of Mayo map area (Roots, 1997). Intrusion of Anvil plutonic suite McArthur Batholith took place between 90-95 Ma (Roots, 1997). Magmatism post-dated the penetrative deformation, and produced wide contact metamorphic aureoles that overprinted penetrative fabrics. Starting in the Eocene, dextral movement along Tintina Fault juxtaposed autochthonous rocks of Selwyn Basin (included in Ddhaw Ghro SMA) to allochthonous Yukon-Tanana Terrane rocks southwest of the fault.

PRELIMINARY GEOLOGY OF SOUTHEASTERN DDHAW GHRO SMA

The geology of southeastern Ddhaw Ghro SMA (Fig. 3) is dominated by the intrusion of McArthur Batholith. Intensely jointed, muscovite-biotite quartz monzonite is ubiquitous, but biotite quartz monzonite and pegmatitic dykes are common. More mafic enclaves are common, particularly along the margins of the batholith. McArthur Batholith contains large pendants reaching over 2 km in diameter. Rocks forming the northeastern-most pendant are resistant, rusty-weathering, pervasively hornfelsed quartz-arenite, siltstone, and shale, and calc-silicate-altered limestone.

Sedimentary rocks in the contact metamorphic aureole are rusty, pervasively hornfelsed or calc-silicate-altered, sub-arkosic to arkosic wacke, shale, siltstone, and minor calcareous siltstone. Primary features are often obliterated. Pervasive alteration precludes definitive stratigraphic correlations. The structurally highest rocks, located to the northeast beyond limits of hornfelsing, may either be part of Road River Group, or a thrust slice of Yusezyu Formation (Hyland Group) over typical Road River Group black shale, chert, and limestone. Hornfelsed siltstone and shale commonly have biotite and chlorite clots up to 5 mm in diameter.

Sedimentary rocks east of Grey Hunter Creek consist of a folded and thrust-imbricated sequence of Duo Lake Formation (dark grey to black chert, shale, and limestone, and minor tan-weathering, medium grey-brown subarkosic wacke), Steel Formation of Road River Group (orange-weathering, greenish-grey, bioturbated, wispy laminated calcareous shale), and Portrait Lake Formation of Earn Group (blue-black-weathering, dark grey to black arkosic wacke and shale). Hyland Group rocks may be present in the area as thin thrust sheets. A resistant, white-weathering, black limestone, interpreted here as the top of Duo Lake Formation, was previously correlated with Hyland Group (Roots, 1996), on the basis of similarity to the regional black limestone defining the contact between Yusezyu and Narchilla formations in Nahanni map sheet (Gordey, 1992). Conodonts from this unit yielded uncertain Paleozoic age (Roots, 1996). The authors of this report collected black limestone samples from five locations for conodont dating. A conspicuous, maroon-weathering, olive-green shale up to 12 m thick, and traced for a strike length of over 2 km, may represent a thin slice of Narchilla Formation thrust imbricated in Duo Lake Formation rocks. Alternatively, maroon and green shale may be part of Nogold Unit, which is visually indistinguishable from Hyland Group rocks, and coeval to upper Road River Group.

STRUCTURAL GEOLOGY

Two phases of deformation produced two penetrative foliations: west-trending folds, S_1 (1st phase, Fig. 4) and northwest-trending folds, S_2 (2nd phase, Fig. 5). Other

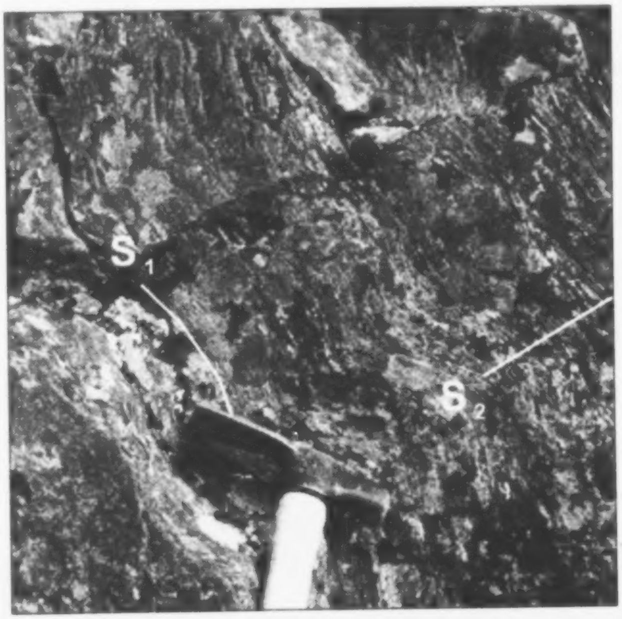

Figure 4. Well developed first (S_1) and second (S_2) phase foliations in pelitic rocks of Road River Group.

significant structures include boudinaged competent beds and veins, and north- to northeast-directed thrusting. Cross-section ABCD (Fig. 6) shows the interpreted structural style of the ridge northeast of Grey Hunter Creek. The contact between competent black limestone and incompetent dark grey shale of Duo Lake Formation represents a plane of weakness along which thrust sheets nucleated during the second deformation event.

CONTACT METAMORPHISM

Within the contact metamorphic aureole of McArthur Batholith, primary textures and foliations are strongly to pervasively overprinted by biotite-hornfels alteration. Small, stubby prismatic metamorphic minerals in aluminous rocks are likely andalusite. Oxidation is moderate to intense. The extent of the contact metamorphic aureole varies between 100 m to over 1 km.

MINERALIZATION

The Sideslip mineral occurrence (105M 039, Yukon MINFILE, 1997) is described as containing mineralized porphyry dyke float. During the 2000 field season, no mineralization associated with the batholith was found in

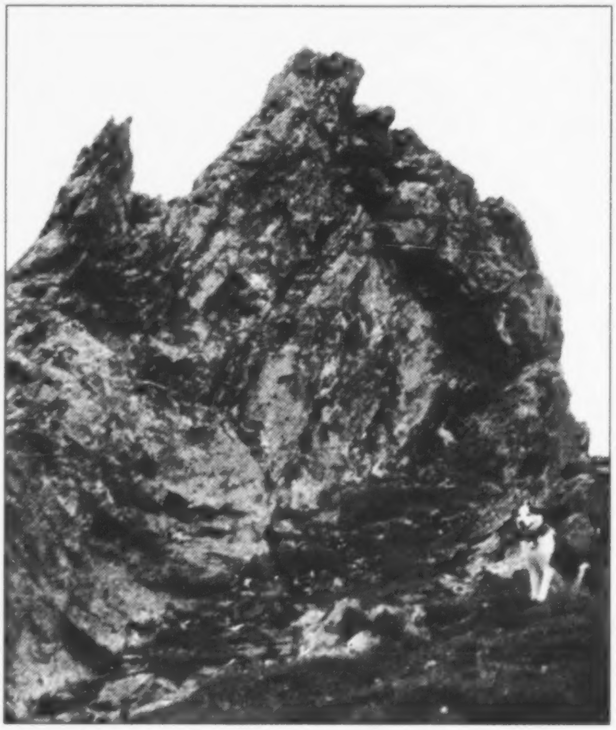

Figure 5. *Folded black limestone (Road River Group or Nogold unit), looking southeast.*

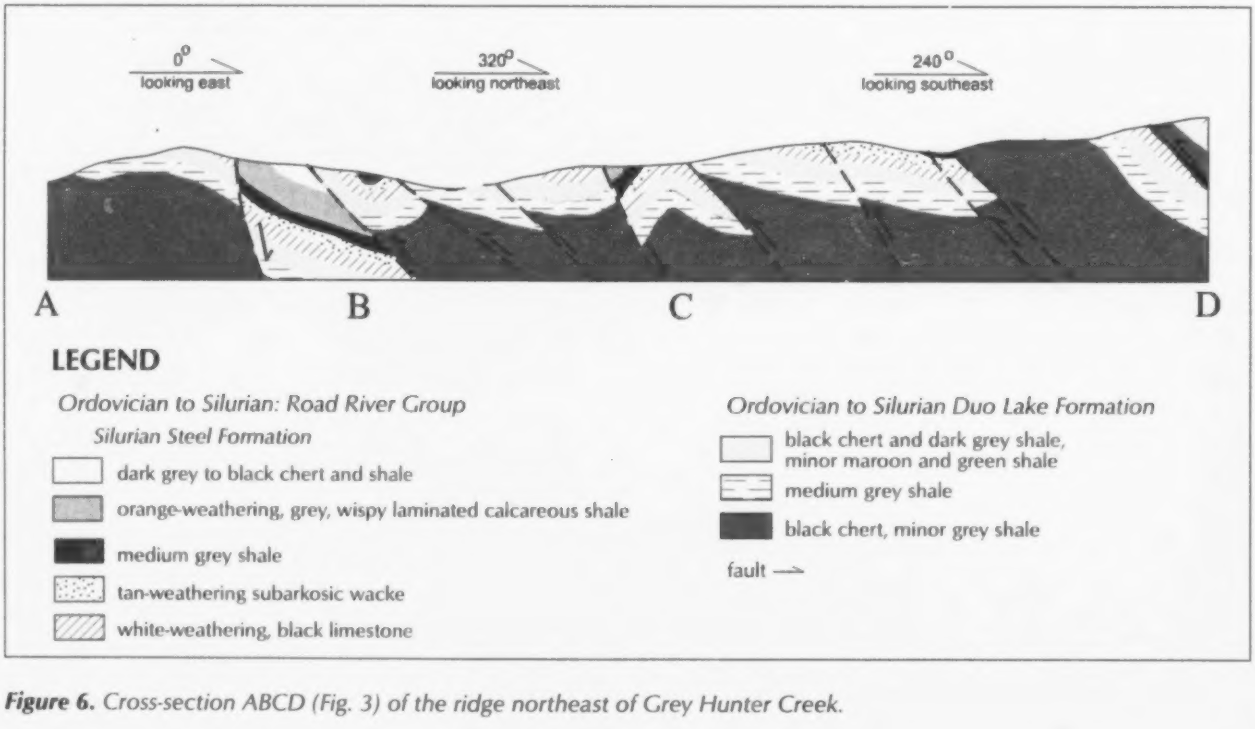
0°
looking east
320°
looking northeast
240°
looking southeast
A
B
C
D
LEGEND
Ordovician to Silurian: Road River Group
Silurian Steel Formation
☐ dark grey to black chert and shale
▒ orange-weathering, grey, wispy laminated calcareous shale
■ medium grey shale
⁙ tan-weathering subarkosic wacke
▨ white-weathering, black limestone
Ordovician to Silurian Duo Lake Formation
☐ black chert and dark grey shale, minor maroon and green shale
☰ medium grey shale
■ black chert, minor grey shale
fault —>

Figure 6. *Cross-section ABCD (Fig. 3) of the ridge northeast of Grey Hunter Creek.*

the Sideslip area. The slope southeast of where the Sideslip mineral occurrence is currently mapped contains skarn with up to 2% pyrrhotite. This mineralization is developed in black limestone interbedded with dark grey shale, in the footwall of an interpreted thrust. Locally, hornfelsed pendants contain up to 10% disseminated sulphides (pyrrhotite and pyrite). In one location, quartz-tourmaline veins crosscut pendant rocks.

SUMMARY AND CONCLUSIONS

The geology of southeastern Ddhaw Ghro SMA consists of folded and thrust-imbricated basinal rocks of Ordovician (Road River Group) to Early Mississippian (Earn Group) age. Some thrust sheets may contain rocks as old as Late Proterozoic to Early Cambrian (Hyland Group).

The mid-Cretaceous McArthur Batholith intruded, produced hornfels and skarn alteration, and obliterated most primary features of the basinal rocks. Plutonic-related mineralization such as intrusive-hosted gold, gold skarn, gold-copper skarn, tungsten skarn, sediment-hosted disseminated gold, and distal polymetallic veins are the most likely styles of mineralization in this geological setting.

Maroon and green shale occurs within typical Road River Group black chert and shale, grey shale and chert, and tan wacke, overlying the Silurian Steel Formation, along with the existence of shallower water facies (limestone) in the Road River Group. This suggests that there is a significant facies change in upper Road River Group in southwestern Mayo map area. It is uncertain whether the facies change results from Silurian rifting or if it represents a transition into a shallower environment to the southwest. New conodont ages and further 1:20 000-scale mapping to the northwest of the McArthur Batholith is necessary to shed light on the age and depositional environment of sedimentary rocks in the various thrust sheets, and to better characterize the deformation style and mineral deposit models applicable to rocks of Ddhaw Grho SMA.

ACKNOWLEDGEMENTS

Danièle Héon is acknowledged for field support, editing and contributing to this text. Charlie Roots provided invaluable information, photographs, and maps. He was always happy to share his expertise and give excellent advice and innovative ideas on geology and field conditions of the Mayo map area. Will Thompson of Trans North provided safe transportation and delicious ice cream. Shirley Abercrombie and Monique Shoniker performed the diplomatic and administrative services that allowed us to do fieldwork.

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Regional mineral resource assessment of Cassiar Terrane and eastern Yukon-Tanana Terrane

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ABSTRACT

In February 2000, Yukon Government Mineral Resources Branch convened a panel of industry geologists to estimate the likelihood of new discoveries in Cassiar Terrane and eastern Yukon-Tanana Terrane. The estimates were processed in a mineral deposit simulator. The simulated tonnage of metal for each tract (approximately 1000 km^2 of coherent geology) was converted to a dollar value, which in turn was used to rank the tracts relative to each other, from lowest to highest mineral potential. Separate runs of the simulator for significant deposit models were completed to produce model specific maps.

RÉSUMÉ

En février 2000, la Direction des ressources minérales du gouvernement du Yukon a convié un groupe de géologues du secteur privé pour estimer la probabilité de nouvelles découvertes dans le terrane de Cassiar et la partie est du terrane de Yukon-Tanana. Les estimations ont été traitées dans un simulateur de gisements minéraux. Le tonnage simulé de métaux pour chaque périmètre évalué (contenant une géologie cohérente sur environ 1000 km^2) a été converti en dollars, valeur ensuite utilisée pour établir le rang des périmètres les uns par rapport aux autres, en commençant par celui présentant le potentiel minéral le plus faible et en terminant par celui dont le potentiel est le plus élevé. Des essais séparés du simulateur pour des modèles de gisements significatifs ont été réalisés afin de produire des cartes propres au modèle.

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INTRODUCTION

Cassiar Terrane and the eastern part of Yukon-Tanana Terrane were the subject of a regional mineral resource assessment. The goal of the assessment was to outline the regional mineral potential of a large portion of the Teslin Tlingit First Nations Traditional Territory, and of the area of interest proposed for the Wolf Lake National Park Feasibility Study. The Cassiar/Yukon-Tanana regional mineral resource assessment area covers over 86% of the Teslin-Tlingit Council Traditional Territory (Fig. 1), as well as parts of the traditional territories of Selkirk First Nation, Little Salmon/Carmacks First Nation, Ross River Dena Council, and Liard First Nation.

REGIONAL MINERAL RESOURCE ASSESSMENT - METHODOLOGY

The methodology used by the Yukon Government for the production of regional mineral potential maps was developed by the United States Geological Survey (USGS; Drew, 1986), and refined by the British Columbia Geological Survey (BCGS; Kilby, 1995) to best fit the Canadian Cordillera. The mineral resource assessment of Cassiar and Yukon-Tanana terranes consisted of seven phases: 1) compilation, 2) definition of tracts, 3) preparation of deposit models, 4) assessment workshop, 5) data entry, 6) Monte Carlo simulation, and 7) ranking.

Regional mineral resource assessments make use of a publicly available geoscientific database, such as geological maps at 1:250 000 and 1:50 000 scale, including the recent bedrock geological compilation by Gordey and Makepeace (1999), regional airborne geophysical surveys, regional stream and lake sediment surveys (Hornebrook and Friske, 1988), and exploration history databases (Yukon MINFILE, 1997). No fieldwork or new data collection was completed.

The assessment workshop took place in February 2000. Five members from industry examined all the geological data one tract at a time, agreed upon which metallic mineral deposit models were pertinent to the tract, and made estimations of the likelihood of finding new deposits of each type in the tract. Each member recorded their confidence in the current knowledge of the geology of the tract, and distributed 100 points between the other four estimators to record their confidence in their knowledge and experience. The estimation data was digitized and processed by a Monte Carlo statistical simulator, which compares the estimations with grades and tonnages of existing deposits worldwide. Another software application converts simulated tonnages to dollar values, which are used to rank the tracts from highest to

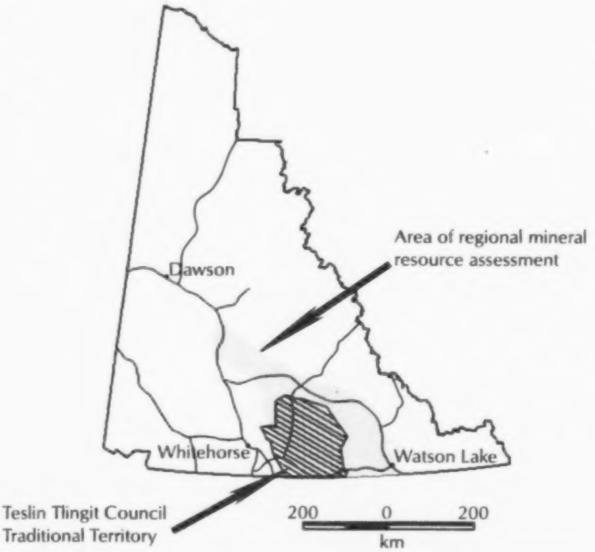
Area of regional mineral resource assessment
Dawson
Whitehorse
Watson Lake
Teslin Tlingit Council Traditional Territory
200
0
200
km

Figure 1. *Location map displaying the area of this regional mineral resource assessment, and the Teslin Tlingit First Nation Traditional Territory.*

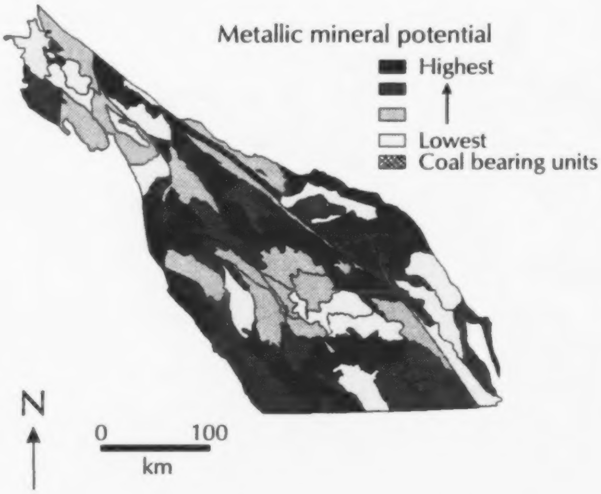

Figure 2. *Mineral potential map of Cassiar Terrane and eastern Yukon-Tanana Terrane.*

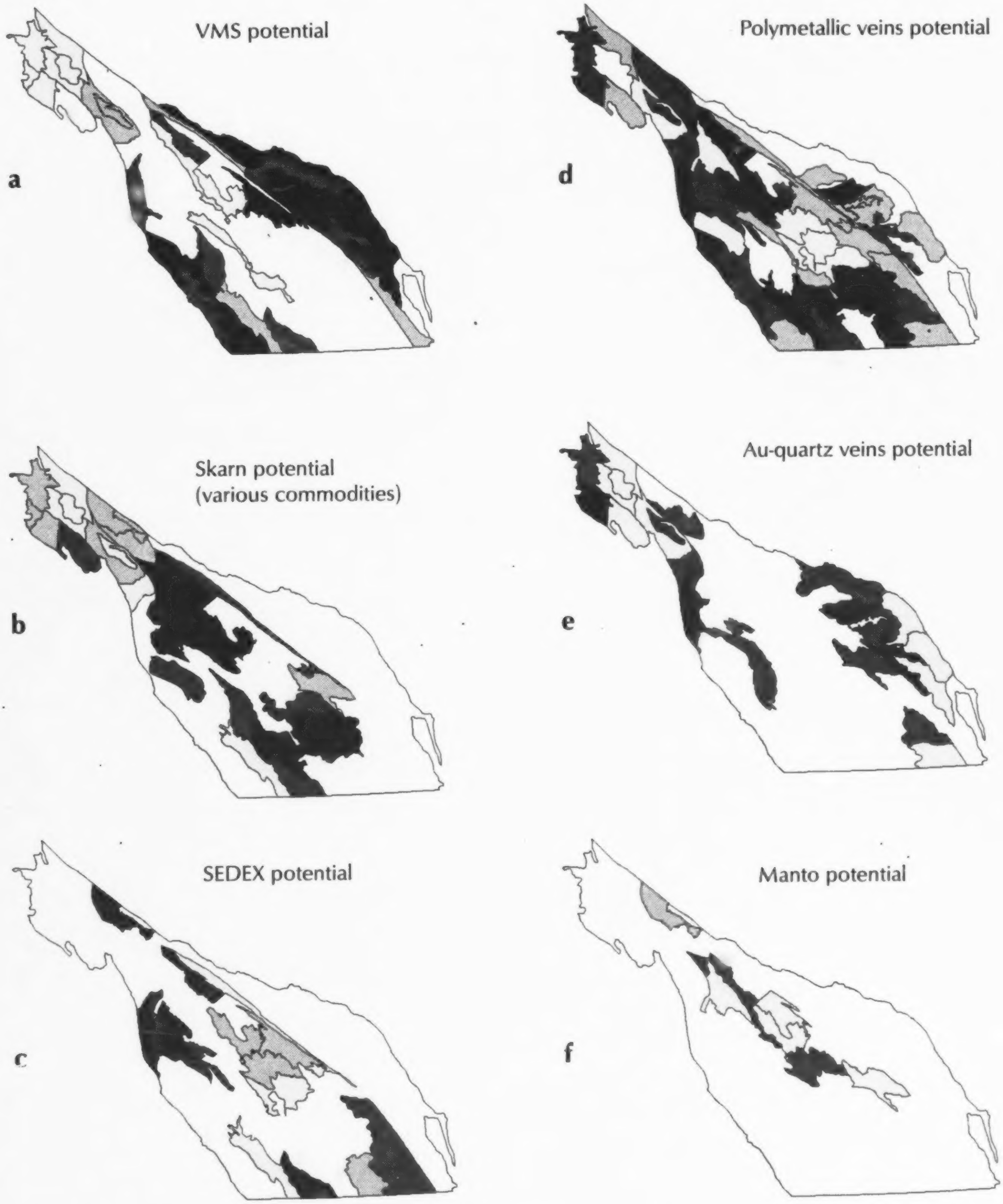
VMS potential
a
Polymetallic veins potential
d
Skarn potential (various commodities)
b
Au-quartz veins potential
e
SEDEX potential
c
Manto potential
f
Highest
Lowest
N
0
100
km

Figure 3. *Map of potential for (a) volcanogenic massive sulphide (VMS) deposits; (b) skarn deposits; (c) sedimentary exhalative (SEDEX) deposits; (d) polymetallic vein deposits; (e) gold-quartz vein deposits; and (f) polymetallic manto deposits.*

lowest potential. Separate runs of the simulator were also completed for individual deposit models.

The regional mineral potential map (Fig. 2) shows a relative rank, from highest to lowest potential for a variety of mineralization styles and commodities. Figure 3 displays maps of potential for specific mineral deposit models.

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Placer depositional settings and their ages along Dominion Creek, Klondike area, Yukon[1]

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Froese, D.G., Enkin, R.J. and Smith D.G., 2001. Placer depositional settings and their ages along Dominion Creek, Klondike area, Yukon. *In:* Yukon Exploration and Geology 2000, D.S. Emond and L.H. Weston (eds.), Exploration and Geological Services Division, Yukon, Indian and Northern Affairs Canada, p. 159-169.

ABSTRACT

Dominion Creek and its tributaries (Sulphur and Gold Run creeks) are one of the largest placer gold producing areas in North America. The placer gravel is divided into: (1) Pliocene White Channel gravel, (2) Pleistocene terraces, (3) early Pleistocene incised-valley gravel (Ross gravel), (4) Pleistocene Dominion Creek gravel, and (5) creek and gulch deposits.

Paleomagnetically, the White Channel gravel is normally magnetized at one site, suggesting a pre-Brunhes normal chron (likely recording the Gauss chron, or an earlier sub-chron older than 2.6 million years). These results are broadly similar to those paleomagnetic investigations of the White Channel gravel in the Klondike River drainage. The Ross gravel is magnetically reversed and may be correlated to the Matuyama reversed chron (older than 780,000 years). Furthermore, the Ross gravel has a younger normally magnetized alteration overprint presumably of Brunhes age (younger than 780,000 years). Dominion Creek gravel overlies the Ross gravel in lower Dominion, Sulphur and Gold Run creeks, and at all sites sampled revealed normal polarity, presumably of Brunhes age (younger than 780,000 years). Radiocarbon ages from the Dominion Creek gravel range from older than 47,000 years BP to 6000 years BP, and likely represent a composite unit of fluvial activity over the last several hundred thousand years.

The oldest and volumetrically largest placer deposits are associated with the Ross gravel, and little gold appears to have been subsequently mobilized from bedrock sources during the last 800,000 years. Gold within Dominion Creek deposits is largely flat, rounded and well travelled, suggesting the main source was likely near King Solomon Dome in the headwaters of the basin.

RÉSUMÉ

Le cours d'eau Dominion et ses tributaires (cours d'eau Sulphur et Gold Run) est l'une des régions productrices d'or placérien les plus importantes en Amérique du Nord. Le gravier alluvionnaire est divisé en : (1) gravier de White Channel du Pliocène, (2) terrasses du Pléistocène, (3) gravier d'ancienne vallée fluviale du Pléistocène inférieur (gravier de Ross), (4) gravier du cours d'eau Dominion du Pléistocène et (5) dépôts dans des ruisseaux et ravins.

Sur le plan paléomagnétique, le gravier de White Channel est normalement magnétisé à un endroit, suggérant un chrone polaire normal pre-Brunhes (indiquant vraisemblablement le chrone polaire normal de Gauss ou un sous-chrone antérieur de plus de 2,6 millions d'années). Ces résultats sont largement semblables à ceux d'études paléomagnétiques du gravier de White Channel dans le drainage de la rivière Klondike. Le gravier de Ross est magnétiquement inversé et peut être corrélé au chrone polaire inverse de Matuyama (plus de 780 000 ans). En outre, il est superposé d'une altération normalement magnétisée plus jeune datant probablement de l'époque de Brunhes (moins de 780 000 ans). Le gravier du cours d'eau Dominion couvre le gravier de Ross dans la partie inférieure des cours d'eau Dominion, Sulphur et Gold Run et, à tous les sites échantillonnés, a présenté une polarité normale, probablement de l'époque de Brunhes (moins de 780 000 ans). D'après la datation au C^{14}, le gravier du cours d'eau Dominion remonte à une époque de plus de 47 000 ans B.P. à 6000 ans B.P. et représente probablement une unité composite d'activité fluviale au cours des dernières centaines de milliers d'années.

Les gisements placériens les plus anciens et les plus importants sur le plan volumétrique sont associés au gravier de Ross, et une quantité infime d'or semble avoir été mobilisée par la suite des sources de substratum rocheux durant le 800 000 d'années. L'or dans les dépôts du cours d'eau Dominion est largement plat, arrondi et a été transporté sur de longues distances, suggérant que la source principale se trouve probablement près du dôme de King Solomon dans le cours supérieur du bassin.

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INTRODUCTION

Dominion Creek and its tributaries (principally Sulphur and Gold Run creeks) reported production of roughly 450,000 ounces of raw gold (14 million grams) between 1978 and 1997 (Mining Inspection Division, 1998). This value represents a small fraction of the creek's total production since discovery in 1896, which is likely close to 3 million ounces (80 million grams; Table 1). Despite the economic significance of these deposits, systematic regional surficial mapping, and descriptions and ages of the producing deposits have not yet been completed. During July and August of 2000, as part of the Stewart River NATMAP (National Mapping Program) project, fieldwork was carried out along Dominion Creek and its tributaries to support regional surficial geology mapping. The purpose of this preliminary study is to provide a sedimentologic description of deposits, their paleomagnetism, and document associations between geomorphic and placer gold settings. A more complete account, including the results of additional analytical studies of samples collected in this study, will be included with the final report on the surficial geology of the Klondike Placer District.

Table 1. *Mining history and placer gold production since discovery on Dominion, Gold Run and Sulphur creeks.*

Hand mining 1896-1906[1]	**Estimated production (fine ounces)**
Reported production Dominion, Gold Run and Sulphur creeks	**~1 million**
Dredging (1913-1966)[2]	
Dominion Creek dredges	
NW#1, YCGC#1 1921-1938	125,000
NW#2, YCGC#5 1921-1966	315,000
YCGC #10 1939-1964	178,000
YCGC#12 1954-1960, 1963-1965	28,000
Gold Run Creek dredges	
YGC #6 1914-1923	70,000
Sulphur Creek dredges	
YCGC #6 1936-1966	148,000
YCGC #8 1937-1966212 000YCGC #9 1938-1966	113,000
Mechanized mining (1978-present)[3]	
Dominion, Sulphur and Gold Run creeks	~450,000 oz (raw)
TOTAL PRODUCTION	**> 2.6 million oz (> 80 million g)**

[1] Figure reported in McConnell, 1905

[2] Dredge production values estimated from volume and history reported in Green, 1977 using an average grade of 0.01 oz/yd^3 (0.23 g/m^3)

[3] Production provided by Mining Inspection Division (1998) and W. LeBarge (pers. comm., 2000). NW- Northwest Mining Company, YGC- Yukon Gold Corporation, YCGC- Yukon Consolidated Gold Corporation

REGIONAL SETTING

Dominion Creek is the largest tributary of Indian River, and forms the southeastern boundary of the Klondike placer district (Fig. 1). Near the junction with Jensen Creek, Dominion Creek turns sharply to the south, continuing to its confluence with Gold Run and Sulphur creeks. It becomes the Indian River below that point.

The Dominion Creek basin is located within the Yukon-Tanana Terrane and consists largely of metasedimentary and metavolcanic rocks at chlorite-biotite to garnet metamorphic grade (Mortensen, 1990, 1996). Lode gold occurrences are associated with metavolcanic rocks of the Klondike Schist and mesothermal quartz veins (Mortensen et al., 1992). The erosion of mesothermal quartz veins appears to be the main source of the Klondike placer deposits based upon elemental similarities (microprobe geochemistry) between placer and lode gold (Knight et al., 1999b). Erosion of bedrock sources and transport by fluvial processes is supported on Dominion Creek by hydraulic equivalence data amongst gravelly depositional unit grain size and size/weight of gold grains recovered from placer gravel (Christie, 1996).

PREVIOUS WORK

Little systematic work has been completed on the surficial sediments which host the local placer deposits since the pioneering work of R.G. McConnell (1905). Most studies in the Klondike region have focused on the more accessible Hunker and Bonanza creeks. Milner (1976) studied the geomorphology of the Klondike goldfields, interpreted a series of lineaments through the Dominion Creek area and discussed gold fineness values in the district. Lowey (1999) described the sedimentology of some placer deposits on Dominion Creek. Fraser and Burn (1997), and Kotler and Burn (2000) studied valley-bottom, loess-dominated 'mucks' and related permafrost features associated with late Pleistocene deposits in the Klondike, including two sites in upper Dominion Creek (Fig. 1).

Regional Quaternary glacial limit compilations have been completed along the margins of the Dominion Creek drainage by Bostock (1942, 1966), Hughes et al. (1969),

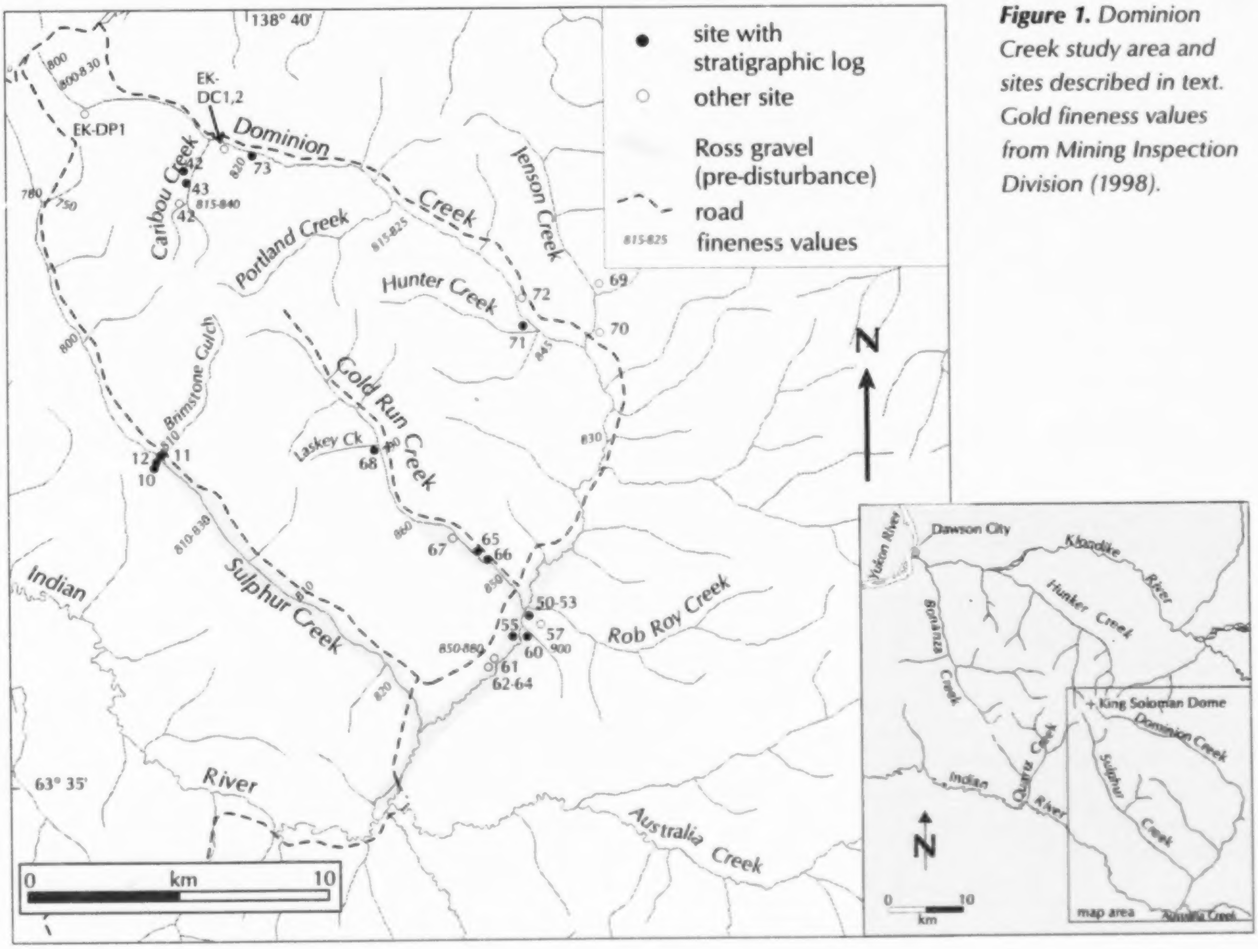
138° 40'
● site with stratigraphic log
○ other site
Ross gravel (pre-disturbance)
road
815-825 fineness values
EK-DC1,2
EK-DP1
Dominion Creek
Caribou Creek
Portland Creek
Jenson Creek
Hunter Creek
Gold Run Creek
Laskey Ck
Brimstone Gulch
Sulphur Creek
Indian River
Rob Roy Creek
Australia Creek
N
63° 35'
0 km 10
Dawson City
Yukon River
Klondike River
Hunker Creek
Bonanza Creek
Quartz Creek
Indian River
King Solomon Dome
Dominion Creek
Sulphur Creek
map area
Australia Creek
0 10 km

Figure 1. Dominion Creek study area and sites described in text. Gold fineness values from Mining Inspection Division (1998).

and most recently by Duk-Rodkin (1999). These studies and more recent chronology (Froese et al., 2000) indicate that late Pliocene glaciers advanced in Tintina Trench, north of Dominion Creek, to the headwaters of Jensen Creek and may have deposited meltwater down this tributary to Dominion Creek (Fig. 1). However, no erratics were found on Jensen Creek. A likely coeval meltwater discharge event from ice over-topping the divide between the Stewart River and Australia Creek deposited extensive outwash down the Indian River, below Dominion Creek.

METHODS

Most sites were visited in the study area during July and August, 2000 in the course of surficial geology mapping. A few additional sites were described by the first author between 1997 and 1999 (Froese, 1997; Froese et al., 1999). Thirteen sites were the subject of detailed sedimentologic descriptions. Exposures were cleaned with shovels and trowels, then photographed, documented and sampled. Detailed vertical lithostratigraphic logs were measured on a bed-by-bed basis, and where exposures allowed, horizontal sedimentary logs were collected noting lateral variation and facies changes within units. Sections were initially subdivided into stratigraphic units on the basis of sediment type, and general sedimentologic features. Orientation of gravelly cross-beds and clast imbrication was measured with a Brunton compass. Samples were collected from representative units for grain size, heavy minerals, gold content, pebble lithology, tephra and macrofossil (bone material and paleoecology) identification. As well, oriented paleomagnetic samples were collected from fine-grained (clay to fine sand) deposits to establish chronology (methods described in paleomagnetism section below). Heavy mineral and tephra identifications are not yet complete, and only preliminary paleomagnetic results are available. Results of the analytical work will be included in the final report.

GRAVEL STRATIGRAPHY

Dominion Creek fluvial deposits are divided into (1) Pliocene terraces (equivalent to White Channel gravel), (2) Pleistocene terraces, (3) incised-valley-fill gravel (Ross gravel), (4) Dominion Creek gravel, and (5) gulch and stream deposits. These relations are shown in Figure 2 and lithostratigraphic logs from sites described during fieldwork in Figure 3.

PLIOCENE TERRACES (WHITE CHANNEL GRAVEL EQUIVALENT)

Pliocene terraces of Dominion Creek and its tributaries are generally poorly preserved. These terraces are assumed to be correlative to the White Channel gravel that is well established on the Klondike River side of King Solomon Dome (Morison, 1985; Froese et al., 2000). In the drainages of Bonanza and Hunker creeks, the White Channel gravel is early to mid-Pliocene (>2.6 Ma) and is dominated by pre-glacial pollen assemblages (Schweger et al., in review).

Exposures from suspected White Channel-equivalent gravel on Dominion Creek are found along middle Caribou Creek (Fig. 1, site 41), and in exploration trenches on a series of high bench gravel deposits along lower Dominion Creek (Fig. 1, site 57). The Caribou Creek site (Fig. 1, site 43) is ~20 m above the modern valley bottom and consists of 2 m of poorly sorted, sand-matrix-filled cobbly gravel. Weak cross-bedding in the gravel suggests this was a braided-river system with abundant contributions of sediment from local hillslopes. A 5-cm-thick tephra was sampled from overbank sediment within the gravel, indicating a period of exposure in which the tephra was deposited on the bar surface. Identification of the tephra later this year should allow a better estimate of the Caribou Creek terrace age.

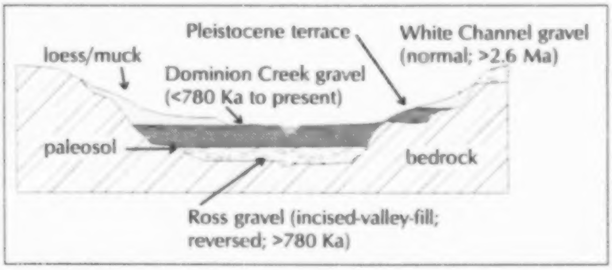
Pleistocene terrace
White Channel gravel (normal; >2.6 Ma)
loess/muck
Dominion Creek gravel (<780 Ka to present)
paleosol
bedrock
Ross gravel (incised-valley-fill; reversed; >780 Ka)

Figure 2. Generalized section across terrace gravel of Dominion Creek near the mouth of Gold Run Creek. Normal and reverse refer to remanent polarity recorded in sediments.

Christie (1992) completed assessment work on the Gyppo and Eagle benches (surfaces 45 m above the modern creek) along the east side of Dominion Creek (Fig. 1, site 57). During the course of that work he excavated a series of test-trenches and backhoe holes to determine the depth and distribution of the placer gold deposit and its potential. From the assessment report we can establish a gravel thickness of at least 7.5 m with a clay-rich surface (soil-weathering zone) of up to 1.7 m (Christie, 1992). This depth of clay development is characteristic of the Wounded Moose soil that is of similar depth on the White Channel gravel on lower Bonanza Creek (Smith et al., 1986). Unfortunately, the holes were back-filled and no exposures remain of the trenches, but we were able to establish that pebble lithology from surface tailings was 80% quartz (based on 200 clasts) with the remaining being a variety of locally derived schists. Clast size in the deposit is variable, and boulders up to 70 cm across (smallest axis) are common.

PLEISTOCENE TERRACES

Pleistocene fluvial terraces, intermediate in elevation between the Pliocene terraces and the modern valley bottom (>10 m above the modern creek levels), are poorly preserved. Terraces were only identified from airphoto interpretation, and no exposures were located.

ROSS GRAVEL (INCISED-VALLEY GRAVEL)

Ross gravel, as it is defined here, is volumetrically the most significant source for placer deposits on Dominion Creek. Locally, it has been called 'White Channel gravel' due to its bleached appearance and similarity to Pliocene White Channel gravel on Bonanza and Hunker creeks (McConnell, 1905). However, stratigraphic work in this paper indicates Ross gravel is significantly younger than 'White Channel gravel' as it is known north of King Solomon Dome. On Dominion Creek, Ross Gravel is incised up to 40 m into the White Channel Terrace. Therefore, we propose the name 'Ross gravel' after the Ross Mining camp where it is well exposed and mined on Dominion Creek.

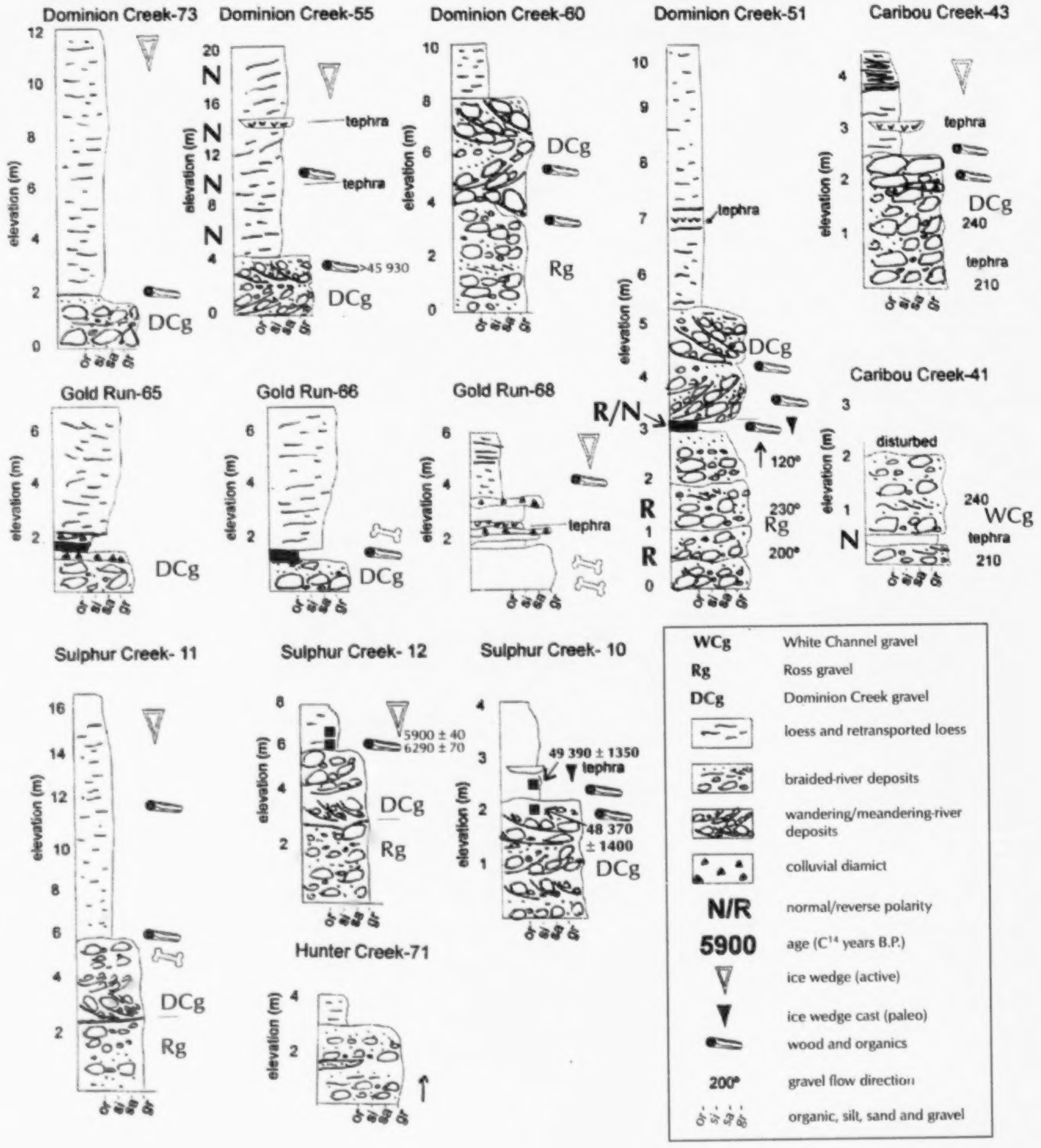
Dominion Creek-73
Dominion Creek-55
Dominion Creek-60
Dominion Creek-51
Caribou Creek-43
elevation (m)
tephra
>45 930
DCg
Rg
N
R
R/N
120°
230°
200°
240
210
Caribou Creek-41
disturbed
WCg
Gold Run-65
Gold Run-66
Gold Run-68
Sulphur Creek- 11
Sulphur Creek- 12
Sulphur Creek- 10
5900 ± 40
6290 ± 70
49 390 ± 1350
48 370
± 1400
Hunter Creek-71
WCg White Channel gravel
Rg Ross gravel
DCg Dominion Creek gravel
loess and retransported loess
braided-river deposits
wandering/meandering-river deposits
colluvial diamict
N/R normal/reverse polarity
5900 age (C14 years B.P.)
ice wedge (active)
ice wedge cast (paleo)
wood and organics
200° gravel flow direction
organic, silt, sand and gravel

Figure 3. Lithostratigraphic logs (generalized) at sites with detailed sedimentologic descriptions. Some sites were sampled for paleomagnetism. All lithostratigraphic logs rest on bedrock. See Figure 1 for site locations.

Ross gravel is a characteristically light grey to white, quartz-rich gravel that occurs below the modern (prior to mining disturbance) creek level on Dominion, Sulphur and Gold Run creeks (Fig. 3). On Dominion Creek, this gravel can be observed in mining exposures between the mouths of Sulphur and Jensen creeks (Fig. 1) and probably extends further down-valley. Drill records and mining reports (G. Klein pers. comm., 2000) indicate a likely equivalent, quartz-rich white gravel extended up Sulphur Creek to at least Brimstone Gulch and Gold Run Creek to just below Laskey Creek (Fig. 1).

Pebble counts of Ross gravel on Dominion Creek are roughly 80% vein quartz with remaining lithologies consisting of locally derived schists and metavolcanic rocks. Sedimentologically, the Ross gravel consists mainly of massive and imbricate matrix-filled gravel with secondary occurrences of matrix-filled and normal-grading, crudely-stratified gravel. The upper boundary of the Ross gravel is a well defined floodplain soil (Fig. 4) that accumulated on the surface of the ancestral Dominion Creek floodplain, however at some sites, the surface soil is not present, having been eroded by the Dominion Creek gravel.

The massive gravel is interpreted as channel and bar deposits in a system with abundant bedload. The crude stratification and normal grading of the gravel likely

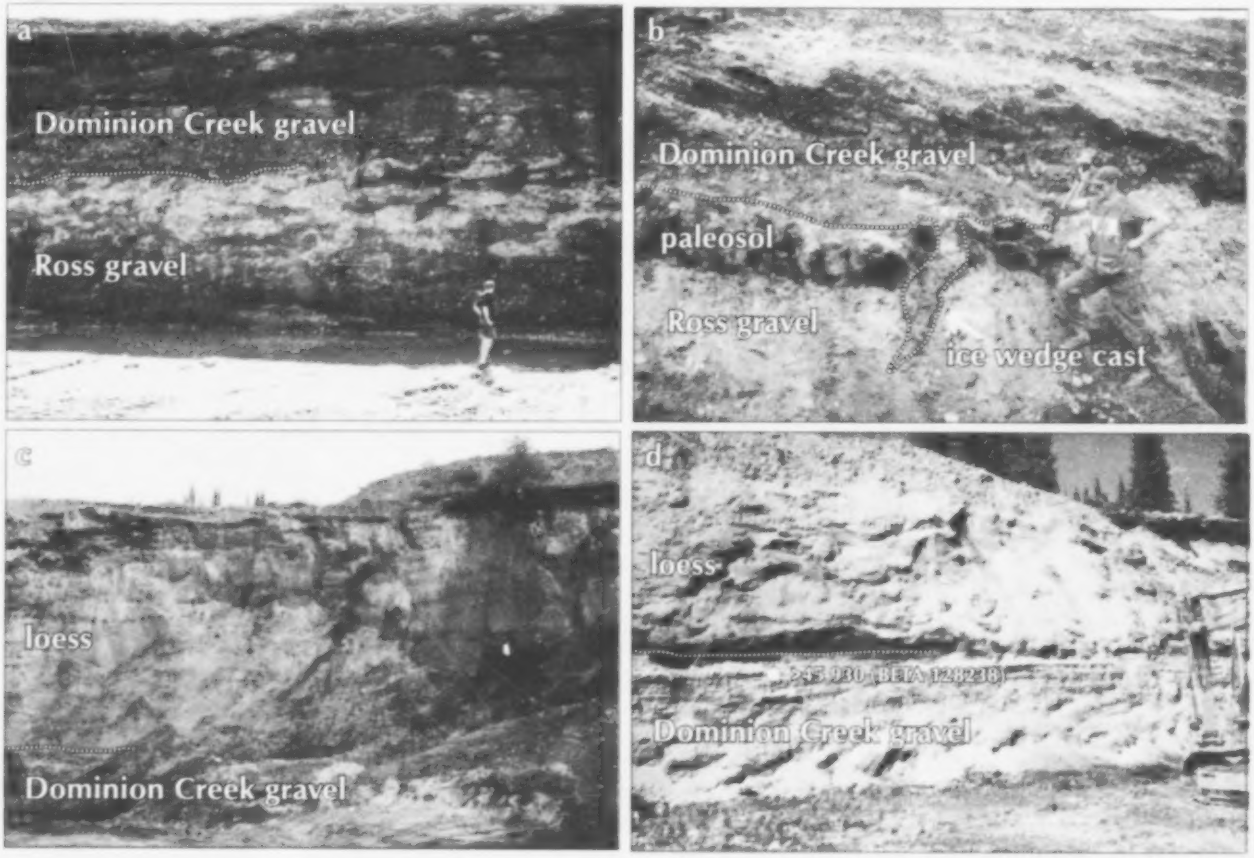

Figure 4. *(a) Ross gravel and Dominion Creek gravel exposed in 1995 at site 59. The Ross gravel has a bleached appearance due to post-depositional fluid flow. (b) Ross gravel with soil and ice-wedge cast cutting paleosol at site 51. Paleomagnetism of the Ross gravel indicates a primary reverse with a secondary normal (overprint) associated with post-depositional fluid migration through the gravel. The primary reverse indicates an age of >780,000 years. (c) Dominion Creek gravel with normally magnetized loess (site 55). (d) Dominion Creek gravel at site 55 where wood collected within the upper gravel yielded a* C^{14} *age of >45,930 years (BETA 128238).*

represents the distal end of hyper-concentrated flows. The enrichment of quartz at the expense of weaker lithologies suggests a system with abundant sediment inputs from both fluvial and local hillslopes that were incised and reconcentrated over an extended period of time (perhaps several hundred thousand years). Ice-wedge casts cross-cutting the soil indicate continuous permafrost conditions were present, at least locally, following soil development.

DOMINION CREEK GRAVEL

Dominion Creek gravel refers to the gravelly deposits of Dominion, Gold Run and Sulphur creeks overlying the Ross gravel, and occupying main valleys of these creeks. In some examples (Hunter Creek - site 71, and Sulphur Creek - site 10, Fig. 1), the gravel is related to a more recent aggradation of the valleys (in perhaps the last 50 Ka or less). However, since they are difficult to trace much beyond local sites, these deposits are included with Dominion Creek gravel. At some sites, Dominion Creek gravel is overlain by massive and retransported silt, which accumulated from deposition and retransportation of regional loess. Loess thickness is greatest at tributary junctions.

Near tributary junctions, Dominion Creek gravel consists of massive to weakly stratified gravel and may include matrix-supported deposits. In main valley settings, particularly below Gold Run Creek, where it overlies Ross gravel, Dominion Creek gravel consists largely of stratified lateral accretion facies, indicating a meandering to wandering gravelly stream during deposition.

CREEK AND GULCH DEPOSITS

Creek and gulch deposits occur in the upper 1-5 km of the main valley and low-order tributaries to Dominion Creek. These areas have limited run-off, which contributes to more poorly sorted, massive deposits with greater concentrations of material derived from local slopes compared with main valley deposits. This results in massive, poorly sorted cobble gravel, frequently interbedded with hillslope deposits, and generally overlain by irregular thicknesses (up to 15 m) of retransported loess and organic material (locally 'muck'). Fraser and Burn (1997) indicate these deposits began accumulating during the late Wisconsin climate interval (last glaciation ca. 30 Ka B.P.), but may in fact have accumulated during multiple episodes in the past (Kotler and Burn, 2000), and some remnants may be >200 Ka (Preece et al., 2000).

PALEOMAGNETISM

Oriented samples were collected within fine-grained overbank sediments in gravel deposits, while loess deposits were sampled with a minimum vertical interval of 20 cm. Where contacts with adjacent facies were sharp, as in the case of overbank deposits, additional samples were collected horizontally to obtain at least seven samples from units to determine polarity. Sediments were collected by cleaning the exposure to a vertical face and inserting plastic cylinders (2.5 cm diameter) horizontally. Sample azimuths were measured using a magnetic compass. Remanence measurements were made on an AGICO JR-5A spinner magnetometer. Stepwise alternating field demagnetization was carried out using a Schonstedt GSD-5 with peak fields up to 100 mT. Samples were demagnetized using 5-10 steps and directions determined by principal component analysis (Kirschvink, 1980).

SUMMARY OF MAGNETOSTRATIGRAPHY

Table 2 provides a summary of sampling sites and polarity data by site and stratigraphic unit. Lithostratigraphic logs of sections and sampling locations are shown graphically in Figure 3.

White Channel gravel

Paleomagnetic samples from Caribou Creek were collected 3 m above bedrock in an overbank sandy-silt

Table 2. *Summary of paleomagnetic remanence directions.*

Site	n	D (°)	I (°)	k	α_{95}	Polarity
Dominion Creek gravel						
Hunter Creek	6	28	82.2	79	7.6	N
Site 55 (loess)	5	11.1	76.4	24.1	15.9	N
Site 55 (loess)	3	66.2	67.0	112.4	11.7	N
Site 55 (loess)	10	316.5	67.1	54.8	6.6	N
Site 55 (loess)	3	282.5	39.1	42.7	19.1	N
Ross gravel						
Ross gravel (overprint)	15	63.8	80.9	15.7	10.1	N
Ross gravel	10	171.2	-39.1	4	28.6	R
White Channel gravel						
Caribou Creek	5	106.8	68.6	4.1	34.0	N

Note: n, number of samples; D and I, declination and inclination (respectively) of the mean remanence direction; k, precision parameter; α_{95}, circle of confidence ($p=0.05$); N and R, normal and reverse magnetization (respectively).

adjacent to a prominent tephra. The samples are normally magnetized, indicating deposition during a pre-Brunhes normal interval, likely the Gauss chron (>2.6 Ma).

Ross gravel

Thirty samples were collected within the Ross gravel at site 51 (Fig. 1). Ten samples were collected from an overbank sandy-silt lens about 1 m above bedrock, and ten additional samples were collected from a similar sandy-silt unit 2 m above bedrock. A further ten samples were collected within a floodplain soil near the contact with Dominion Creek gravel. The paleomagnetic samples show a complex magnetization indicating a primary (detrital) reverse magnetization within the gravel with a secondary normal overprint. The secondary overprint is a chemical remanence, which is most strongly recorded within the soil unit, but also extends to samples collected within the underlying gravel. Thus the Ross gravel is interpreted to have been deposited by at least the late Matuyama chron (>780 ka), and subsequently affected by an alteration event during the Brunhes chron (normal <780 ka).

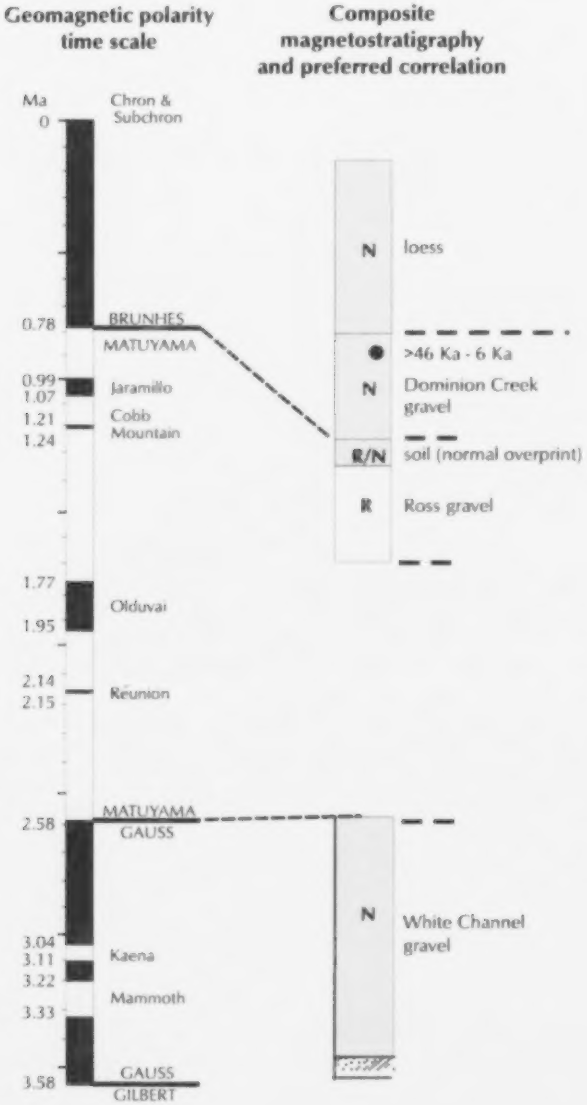
Geomagnetic polarity time scale
Composite magnetostratigraphy and preferred correlation
Ma
Chron & Subchron
0
0.78
BRUNHES
MATUYAMA
0.99
1.07
Jaramillo
1.21
1.24
Cobb Mountain
1.77
Olduvai
1.95
2.14
2.15
Réunion
2.58
MATUYAMA
GAUSS
3.04
3.11
Kaena
3.22
Mammoth
3.33
3.58
GAUSS
GILBERT
N
loess
>46 Ka - 6 Ka
N
Dominion Creek gravel
R/N
soil (normal overprint)
R
Ross gravel
N
White Channel gravel

__Figure 5.__ Preferred correlation of Dominion Creek stratigraphy to the geomagnetic polarity time scale of Cande and Kent (1995).

Dominion Creek gravel

Dominion Creek gravel was sampled within an overbank lens at Hunter Creek where it occurs as a low terrace approximately 5 m above the valley bottom. Six samples from the site determined a normal polarity. At site 55, loess overlying Dominion Creek gravel, was sampled continuously at 15-20 cm intervals and determined a characteristic normal polarity (Table 2). The samples show considerable inter-horizon variability with intra-horizon consistency suggesting that paleo-secular variation was recorded adding confidence that the polarity determined is primary.

CHRONOLOGY

The paleomagnetic data presented in this study does not provide a unique age model for the Dominion Creek deposits, but rather a broad outline of their ages relative

***Table 3.** Radiocarbon ages associated with Dominion Creek gravel. Locations plotted on lithostratigraphic logs in Figure 3.*

Lab no.	Material	C^{14} yrs BP ± 1σ	Significance
BETA-128238	wood	>45,390	wood within DCg on Dominion Creek
TO-7943	twigs	49,390 ± 1350	twigs immediately overlying DCg on Sulphur Creek
BETA-128237	wood	48,370 ± 1400	wood within DCg on Sulphur Creek
GSC-6478	wood	6290 ± 70	wood immediately overlying DCg on Sulphur Creek
BETA-136518	wood	5900 ± 40	*in-situ* stump 1.5 m above DCg on Sulphur Creek

to the geomagnetic polarity time scale. These ages will certainly be refined with the identification and dating of tephra beds found during this study.

Figure 5 is a preferred correlation of the gravel units to the geomagnetic polarity time scale of Cande and Kent (1995). From this correlation we can conclude that the White Channel gravel was deposited during a pre-Brunhes normal polarity chron or sub-chron. Sandhu et al. (this volume) have provided a minimum age for the White Channel gravel on Quartz Creek at 3 Ma, which is consistent with the normal polarity (Gauss 2.6-3.6 Ma). The most surprising aspect of this study, however, is the recognition of the reversed magnetic polarity of the Ross gravel indicating an age of at least 780 Ka for this unit, inferring incision of the Dominion Creek valley to its present position at least by this time.

Dominion Creek gravel sampled at the mouth of Hunter Creek is 5 m above the present valley bottom and is likely mid-late Pleistocene in age, representing a minor aggradation of the valley, post-dating the Ross gravel. Radiocarbon ages from wood collected within the Dominion Creek gravel indicate a wide range from >46 Ka through to 6 Ka (Table 3). Given the position of the modern Dominion and Sulphur creeks (prior to mining) at the level of the Dominion Creek gravel, it is likely this unit spans much of the last several hundred thousand years.

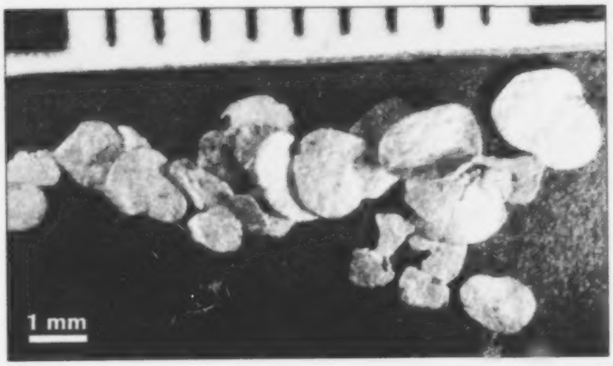

Figure 6. *Typical gold recovered on Dominion Creek near the mouth of Gold Run Creek. Gold tends to be fine grained (majority <2 mm), flat and well rounded, suggesting transport by fluvial process from the headwaters of Dominion and Sulphur creeks in the King Solomon Dome area. Fineness of recovered gold tends to be high (>800) which is consistent with high fineness lode deposits known from the King Solomon Dome area (McConnell, 1905; Knight et al., 1999b).*

PLACER SETTINGS AND GOLD CHARACTER

Fineness values on Dominion Creek (plotted from Mining Inspection Division 1998; Fig. 1) show considerable similarity on each of Sulphur (750-830), Gold Run (790-850) and main Dominion creeks (800-900), and generally increase down-valley, as has been noted previously in the Klondike region (Hester ,1970; Knight et al., 1999b). The increase in down-valley fineness likely reflects prolonged mechanical weathering of gold grains, thus increasing high-fineness rims. Gold morphology data, presented by Knight et al. (1999a), suggests that flat, well rounded gold nuggets, like the majority of those recovered on Dominion and Sulphur creeks, were transported 10-15 km, indicating a major source in the area of King Solomon Dome. A high fineness lode source is well known on King Solomon Dome (McConnell, 1905; Milner, 1976; Knight et al., 1999b).

The majority of gold produced on Dominion, Gold Run and Sulphur creeks in the last century has been from Ross gravel. On Dominion Creek, Ross gravel is at least 800 Ka, suggesting little gold has been eroded or concentrated in the last 800 Ka in this area. This contrasts with the majority of gold produced on Bonanza and Hunker creeks in the Klondike drainage, where deposits are largely of late Pleistocene and Holocene age (valley-bottom gravel/muck ages reported in Fraser and Burn, 1997 and Froese, 1997).

Placer gold recovered on Dominion Creek is generally fine grained (<2 mm), flat and well rounded with few exceptions (Fig. 6). At the mouth of Brimstone Gulch on Sulphur Creek, considerable coarse gold was recovered from mining operations in 1996 with a fineness of 810 (Mining Inspection Division, 1998). Interestingly, not far to the east on Gold Run Creek, considerable coarse gold was recovered near the mouth of Laskey Creek in the summer of 2000. A considerable pay stream below the mouth of Laskey Creek is reported by Nordale (1942) and old-timers thought Laskey Creek was the main source, or at least a very important source for Gold Run Creek (Nordale, 1942).

CONCLUSIONS

1. Stratigraphy and paleomagnetic chronology on Dominion Creek and its tributaries indicates White Channel gravel occurs on high terraces 20-40 m above the present valley bottom.
2. The Dominion Creek valley was incised to its bedrock floor at least 800 Ka during, or preceding, deposition of Ross gravel.
3. The majority of gold on Dominion Creek has been (or is currently) produced from Ross gravel, suggesting little placer formation in the area over the last 800 Ka.

ACKNOWLEDGEMENTS

This study has benefited from the interaction, advice and hospitality from placer miners in the Dominion Creek area. In particular, Jim and Tara Christie, Gerry Klein, Ray Lizotte, and Norm Ross went out of their way to talk about their ground and mining experience in the Klondike. Gerry Klein is also thanked for providing access to YCGC records, including Nordale's (1942) report on Gold Run Creek and other historical materials. In addition, all miners that we approached for gold and heavy mineral samples for our studies readily agreed. John Laughton and Richard Norman provided exceptional field support despite a rainy season and are thanked for their contributions. This study was supported by NSERC and the Stewart River National Mapping Program (NATMAP).

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Tectonic significance of plutonism in the Thirtymile Range, southern Yukon

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ABSTRACT

Two distinct but undeformed suites of granitic plutons intrude deformed siliciclastic rocks in western Dorsey Terrane. A calc-alkaline hornblende-bearing gabbro to granodiorite stock has been dated at 181.5 Ma (by the Rb/Sr method). The second suite consists of highly evolved late-orogenic granites of the Thirtymile stock and Hake Batholith, which are approximately 100 Ma. The penetrative fabric of the metasedimentary rocks indicates generally eastward-vergent layer-parallel shear. The deformation of the siliciclastic rocks is thus constrained at older than 181 Ma. The absence of resetting of the Rb-Sr isotopic ratios of the Jurassic pluton indicates that the mid-Cretaceous magmatism was emplaced at a shallow crustal depth. Since the Jurassic pluton has both a 'juvenile' Sr isotopic ratio of 0.7045 and chemistry indicative of a largely mantle-derived source, a subduction-related setting for magma generation is likely. The spatial relationship of craton-derived clastic rocks and these plutons requires that subduction had an eastward polarity.

RÉSUMÉ

Deux cortèges de plutons granitiques distincts mais non déformés ont pénétré dans les roches silicoclastiques déformées présentes dans la partie occidentale du terrane de Dorsey. Un pluton dont la composition varie de gabbros à des granodiorites calco-alcalines contenant de la hornblende a été daté à 181,5 Ma par la méthode Rb/Sr. Le deuxième cortège est formé de granites tardi-orogéniques très évolués de l'amas Thirtymile et du batholite Hake, dont l'âge est d'environ 100 Ma. La fabrique pénétrative des roches métasédimentaires montre en général un cisaillement de vergence est qui est parallèle aux couches. La déformation des roches silicoclastiques est donc antérieure à 181 Ma. L'absence de remise à zéro des rapports isotopiques Rb-Sr du pluton du Jurassique indique que le magmatisme qui s'est produit au Crétacé moyen s'est mis en place à un niveau crustal peu profond. Puisque le pluton du Jurassique a un rapport isotopique Sr « juvénile » de 0,7045 et une composition chimique indicatrice d'une source provenant principalement du manteau, il est fort probable que ce magma soit le produit d'une zone de subduction. La relation spatiale entre les roches clastiques provenant du craton et les plutons permet de conclure que la polarité de la subduction était orientée vers l'est.

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INTRODUCTION

This paper addresses aspects of regional structure and Rb-Sr characteristics of the Thirtymile (main, southwestern and northeastern bodies) and Hake plutons in south-central Yukon. Other chemical aspects of these intrusions have been described previously (Liverton and Alderton, 1994). These undeformed plutons clearly intrude penetratively deformed metasedimentary rocks, placing an upper limit on the age of deformation. Differences in the age of the intrusions and their Rb-Sr characteristics allow inferences relating to the tectonic history of the Thirtymile Range.

REGIONAL FRAMEWORK

The plutons intrude the Dorsey Terrane of Monger et al. (1991); to the east are Cambrian to Mississippian strata of Ancient North America (the Cassiar Platform); to the west are mylonitized high-grade metamorphic rocks and plutons of the Teslin zone (Gordey and Stevens, 1994; Stevens et al., 1996; Fig. 1). The Thirtymile Range includes the westernmost siliciclastic metasedimentary rocks of Dorsey Terrane (Gordey, 1992; Harms, 1992). They are lithologically similar to lower Paleozoic North American strata and include detrital zircons, which appear to be derived from the neighbouring North American craton and miogeocline (Ross and Harms, 1998). Within Dorsey Terrane are lithostratigraphic assemblages broadly correlative with Yukon-Tanana Terrane (Nelson et al., 2000).

In the Thirtymile Range are plutons of Cretaceous and Jurassic age, and country rocks disrupted by myriad faults. Mylonite zones and inverted beds are reported from the lowest part of the sequence (Gordey, 1991). Tectonic 'slices' of marble within uppermost argillite and also small slices of volcanic rocks in the northern Thirtymile Range may be coeval, suggesting possible imbrication of the succession (Liverton, 1990, 1992). The eastern part of the terrane displays penetrative ductile deformation at its structural base (Stevens and Harms, 1995). Moderate to steeply dipping normal faults in the Range may be either pre- or post-tectonic (thrusting and mylonitization), or both. At least one pair of high-angle normal faults is structurally related to emplacement of the Cretaceous Ork granite stock (Liverton, 1990; 1992).

STRUCTURAL FABRIC OF THE METASEDIMENTARY ROCKS

In the central portion of the Thirtymile Range, wherever a crenulation has been observed in pelites, the axes trend between north-south and 010-190°, with plunges mostly 0-10° in either sense (Liverton, 1992). A mineral elongation has been observed in a few localities; it is parallel to those crenulation axes. Shear-sense indicators, either asymmetry of pressure solution cleavage fabric in the quartzite or C-S fabric in pelitic or calc-silicate lithology, consistently indicate a dextral sense of shear. This translates into top-to-east movement (Fig. 2), an important aspect of the tectonic evolution, considered in the discussion.

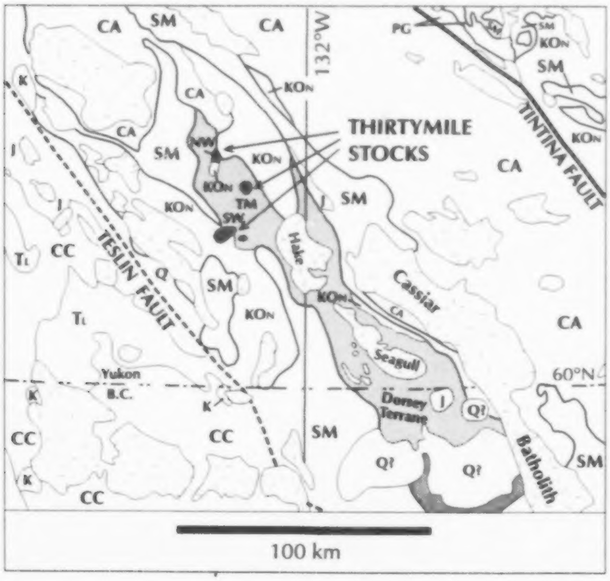

Figure 1. Terrane map of the south-central Yukon after Wheeler et al. (1991). Terranes are: CA = Cassiar; SM = Slide Mountain; CC = Cache Creek; KO$_N$ = Kootenay; Q = Quesnellia; T$_L$ = Lewes River; PG = Pelly Gneiss. K, J = Cretaceous and Jurassic plutons. The Dorsey Terrane is shown in grey. Plutons mentioned are: NW = Northwest Thirtymile; TM = Thirtymile stock (and Ork stock); SW = Southwest Thirtymile; Hake = Hake Batholith; Seagull = Seagull Batholith. The western 'fork' of Dorsey terrane (west of Hake Batholith) contains the siliciclastic assemblages similar to Proterozoic to Paleozoic North American strata.

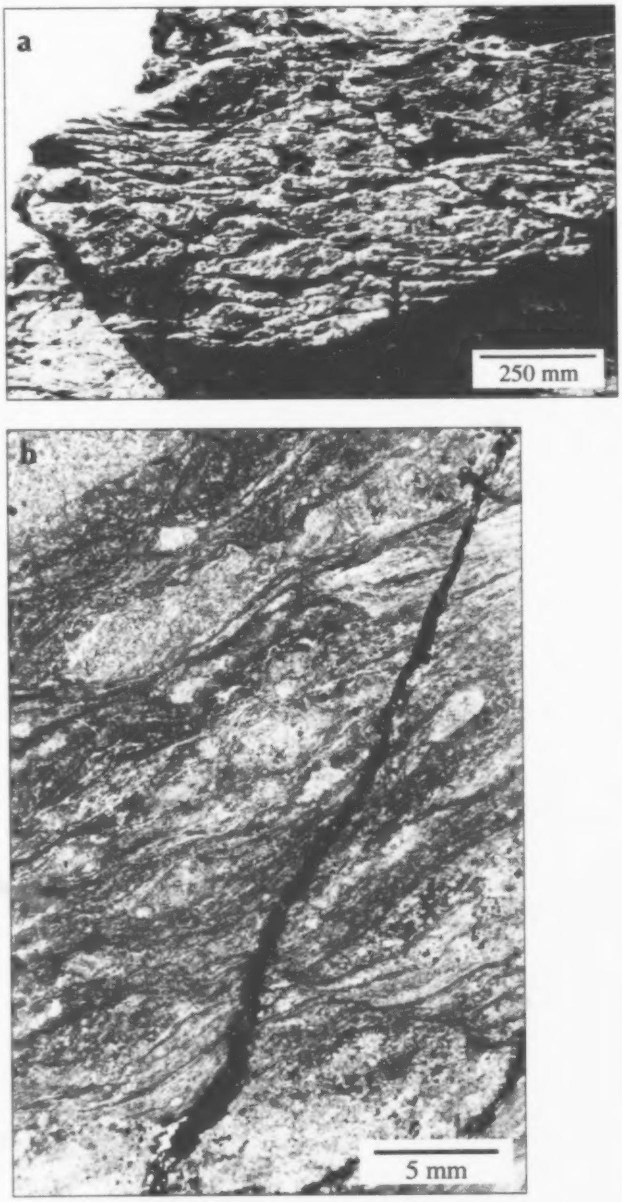

Figure 2. *Two examples of fabrics in Thirtymile Range siliciclastic metasedimentary rocks. (a) Asymmetrical pressure solution cleavage in quartzite. This northward view shows a top-to-east shear sense. Taken in the Thirtymile Range at 60°43'10"N, 132°31'16"W. (b) Thin section is viewed under transmitted light. Boudinage and S-C fabric preserved in calc-silicate hornfels at the Mindy prospect (60°37'33"N, 132°19'34"W). Porphyroclasts are of scapolite/salite and the finer matrix is pyroxene. The crosscutting sulphide vein is a result of skarn overprint. A top-to-southeast (i.e., left) shear sense is indicated.*

PLUTONISM

In southern Yukon are at least two suites of mid-Mississippian plutons (Mihalynuk et al., 1998, 2000; Roots and Heaman, in press), one or more Permian intrusions (Stevens, 1996), an inferred Early or mid-Jurassic tonalite through diorite suite, and Cretaceous plutons (Seagull, Hake and Cassiar batholiths). Among the latter are two mineralogically distinct suites of granitic plutons within the Thirtymile, Englishman's and Dorsey ranges (Fig. 3):

(i) Leucocratic, highly evolved biotite to lepidolite granites *(sensu stricto)* of the Thirtymile and Ork stocks, and Hake and Seagull batholiths (Fig. 1; Liverton and Alderton, 1994). These are sub-alkaline granites (Liverton and Botelho, in press) having a chemical signature closely

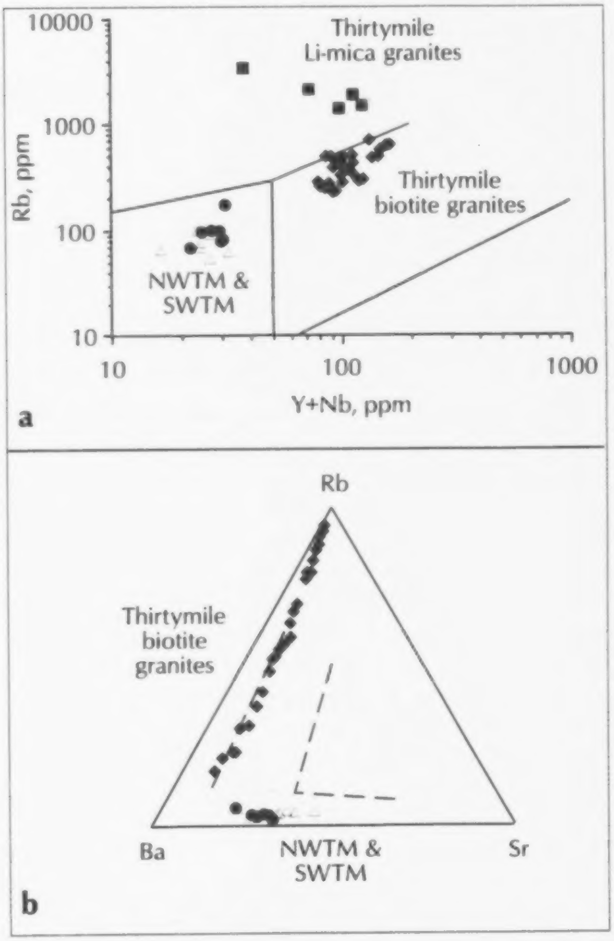

Figure 3. *Tectonic discrimination diagram (a) (Pearce et al., 1984) and Rb-Ba-Sr ternary plot (b) for the Jurassic NW and SW Thirtymile (TM) plutons and the Cretaceous Thirtymile stock.*

resembling the hybrid late-orogenic type (H_{LO}) of Barbarin (1990), and are associated with F-B-Sn ± W contact metasomatic mineralization in the Thirtymile Range. They are one-mica metaluminous to weakly peraluminous granites. Hornblende is present only in the volumetrically inferior, least-evolved porphyry facies of the Thirtymile stock, which is interpreted to be a synplutonic dyke.

(ii) Hornblende-rich granodiorites are present in the Northwest and Southwest Thirtymile stocks (distinct from the main Thirtymile stock, Fig. 1). The two are considered co-magmatic (Liverton, 1992; Liverton and Alderton, 1994) and have similar trace element geochemistry. Their Rb to (Y+Nb) contents place them distinctly in the volcanic-arc granite field (Pearce et al., 1984; details are given in Liverton and Alderton, 1994). The Northwest Thirtymile stock is a mineralogically homogeneous hornblende granodiorite that frequently carries prominent epidote and sphene, has 61.7 - 64.1% SiO2 and a Peacock Index of 55.2. In contrast, the east side of the Southwest Thirtymile stock (cf. hybrid calc-alkaline type, H_{CA} of Barbarin, 1990) consists of sharply discordant gabbro to quartz-diorite intrusions and near-vertical dykes (<1 m wide) that clearly truncate the fabric of the metasedimentary rocks. A large leucocratic hornblende granodiorite extends westward from the more basic body and contains xenoliths of the diorite in the contact region (Liverton, 1992). These lithofacies have a range of 50.9 to 62.0% SiO2 and Peacock Index of 57.4.

ISOTOPIC STUDIES

METHODS

The authors selected four specimens from the Thirtymile megacrystic granite lithofacies (Liverton, 1990) and one from the porphyry for whole-rock Sr isotope determination using the techniques of Thirlwall (1991) on the VG354 mass spectrometer at Royal Holloway, University of London. Rb and Sr contents were determined by X-ray fluorescence spectrometry on pressed pellets, with matrix correction based on major element composition and calibration using international standards analyzed by isotope dilution mass spectrometry. One specimen of mica (zinnwaldite) from a Li-mica topaz leucogranite sill in the main Thirty Mile Stock (#97/28-4 on Fig. 4), one biotite from the Hake Batholith, and one biotite from the granodiorite of the Southwest Thirtymile stock were analyzed for Rb, Sr and $^{87}Sr/^{86}Sr$ by isotope

Figure 4. Sample locations in the Thirtymile stock.

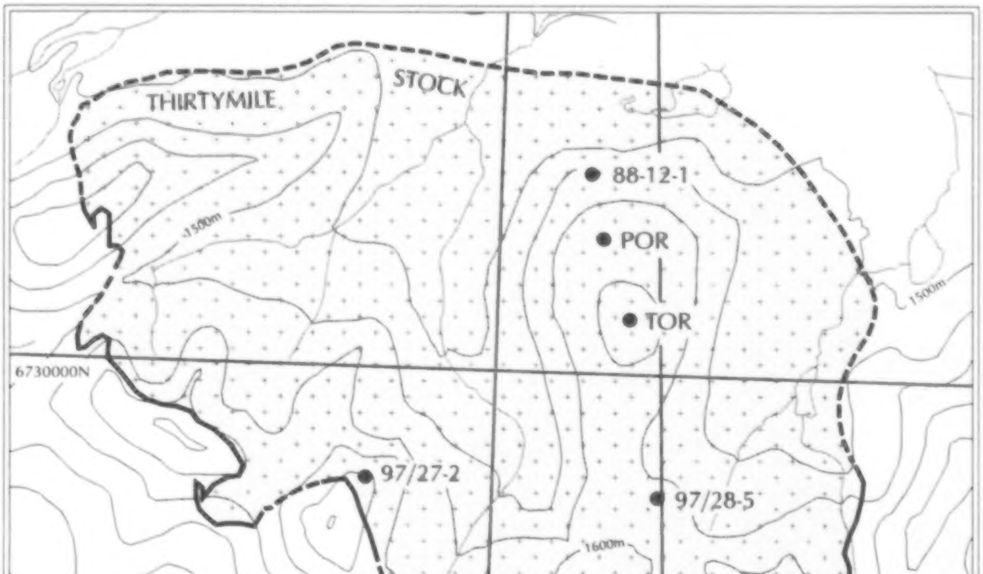

***Table 1.** Summary of chemical data for the Thirtymile plutons and results of Rb-Sr isotopic analyses.*

Pluton	SiO_2	CaO	A/CNK	D	Rb/Sr	Ga/Al
Thirtymile Li-mica	74.1-77.6	0.01-0.23	1.048	86.7-96.3	858-7588	6.69 ± 0.54 (6)
Thirtymile Biotite	70.0-78.0	0.35-1.46	0.919	96.6-99.4	1.8-66.8	3.07 ± 0.28 (31)
NWTM	60.2-64.1	4.36-4.91	0.885	60.9-68.7	006-0.12	2.33 ± 0.04 (5)
SWTM	50.9-62.0	4.44-6.35	0.823	38.4-69.7	0.09-0.13	2.17 ± 0.19 (7)

D = Thornton-Tuttle Differentiation Index; Ga/Al = ppm/%   A/CNK = Al/Ca + Na + K

Pluton/Facies	Specimen		Rb	Sr	Method	Rb/Sr	$^{87}Sr/^{86}Sr \pm 2$ S.E.	$^{87}Rb/^{86}Sr$	Age (Ma ± 2σ)
Thirtymile Megacrystic	97/28-5	Rock	483	73.2	XRF	6.59	0.734721 ± 12	19.06	101 ± 5.6
Thirtymile Megacrystic	TOR	Rock	323	52.2	XRF	6.19	0.733384 ± 9	17.90	
Thirtymile Megacrystic	88/12-1	Rock	394	73.9	XRF	5.33	0.729086 ± 18	15.41	
Thirtymile Megacrystic	97/27-2	Rock	370	110.2	XRF	3.36	0.721347 ± 11	9.70	
Thirtymile Porphyry	POR	Rock	261	147.4	XRF	1.77	0.713364 ± 15	5.10	
Thirtymile Li-mica	97/28-4	Mica	15,491	6.69 ± 0.1	ID		135 ± 5	94379	100 ± 4*
Hake Batholith	08/17-2	Mica	1479	7.38 ± 0.02	ID		1.586 ± 1	627.4	98.3 ± 2.9*
Southwest Thirtymile	08/20-4	Mica	404.0	69.25 ± 0.01	ID		0.74836 ± 8	16.89	181.5 ± 2.5
Southwest Thirtymile	08/20-4	Rock	102.1	961	XRF		0.70529 ± 1	0.3063	

Notes: * Indicates that the age is calculated using $Sr_i = 0.7074$ = initial Sr ratio; S.E. = standard error.

Sample locations other than shown in Fig. 2 are: SW Thirtymile Stock, Specimen 08/20-4: 60°32'17"N, 132°30'00"W, and Hake Batholith, Specimen 08/17-2: 60°26'05"N, 132°01'22"W

dilution. Error in $^{87}Rb/^{86}Sr$ is estimated at <1% (2σ) by repeat analysis of SRM607 K-feldspar. Results of these two sets of measurements are shown in Table 1. Isochrons were calculated using least squares fitting according to the method of York (1969). An isochron diagram for megacrystic granites is Figure 5.

RESULTS

The four ('megacrystic') specimens from Thirtymile stock were used for calculation of the whole-rock errorchron (Fig. 5), which yielded an age of 101 ± 5.3 Ma (2σ analytical error increased by the mean square weighted deviation) and $^{87}Sr/^{86}Sr_i = 0.7074 \pm 0.0011$ (2σ). The isotope ratios of specimen POR (location in Fig. 4) were used to calculate $^{87}Sr/^{86}Sr_i$ for the 'porphyry' lithofacies yielding 0.7060, using t (time) = 101 Ma. Isotope dilution determination of Rb and Sr contents and isotope ratios of zinnwaldite mica from the Li-mica lithofacies of the main Thirtymile stock (sill) indicate that this mineral is sufficiently radiogenic (ratio of Rb:Sr is 2316:1) to allow an age of 100 ± 4 Ma to be calculated using the Sr_i value of the megacrystic facies. This age for the Thirtymile Li-mica lithofacies provides a cooling age for the pluton. Since the mica age is concordant with the whole-rock age, 100 Ma is probably close to the emplacement age of the entire Thirtymile Complex. The Hake pluton yielded an errorchron age of ~98.3 ± 2.9 Ma.

An age of 181.5 ± 2.5 Ma for the Southwest Thirtymile stock was calculated using separated mica from sample 08/20-4, with the corresponding whole rock defining an

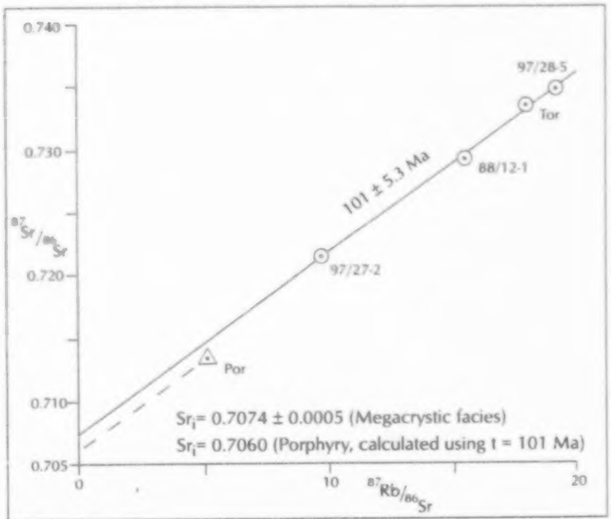

***Figure 5.** Rb-Sr errorchron for the megacrystic facies of the Thirtymile stock.*

initial $^{87}Sr/^{86}Sr$ of 0.7045 ± 0.0003 (2σ). Note that this initial ratio is distinctly lower than those of the main Thirtymile stock facies.

DISCUSSIONS

1. Possible source region of the granites

The Southwest Thirtymile cooling age of 181.5 ± 2.5 Ma is considerably older than those of the main Thirtymile stock (100 ± 4 Ma). This indicates that Cretaceous peak temperatures did not exceed the Rb-Sr blocking temperature for biotite and, hence, that the main Thirtymile stock is likely to have cooled rapidly. This observation is in accordance with the probable shallow depth of emplacement (<<3.5 km) that may be inferred from the presence of miarolitic cavities in several lithofacies of the stock.

The coeval dates calculated for the main Thirtymile stock and Hake Batholith suggest that a single intrusive suite extends southeast; the adjacent Seagull Batholith yielded Rb/Sr dates between 101 ± 4 and 99.8 ± 2.2 Ma (reported in Sinclair, 1986). The Sr-initial ratio ($Sr_i = 0.707$) obtained from the megacrystic facies of the Thirtymile stock, however, is lower than those of the Seagull Batholith, which has a more distinct 'S-type' isotopic signature (0.712; Sinclair, 1986), although it remains markedly higher than those within the Intermontane Belt to the west (usually <0.704; Armstrong, 1988). Mineralogy and chemistry of the Thirtymile pluton (Liverton 1990 & 1992; Liverton & Alderton 1994) are broadly indicative of an ilmenite-bearing, I-type magma, although the Sr-initial ratio suggests that some metasedimentary source rocks are involved in the genesis of this granite (cf. Kistler, 1990). The large radiogenic component of the mid-Cretaceous magmas in general within the Cordillera has been ascribed to elevated lower crustal temperatures at that time. Some of these have no apparent mantle component (Armstrong, 1988).

2. Tectonic model

The tectonic model for the northern Cordillera developed by Struik (1987) is discussed here. Westward-directed subduction of the oceanic Cache Creek Terrane beneath fragments of the continental margin gave rise to the island-arc terrane of Quesnellia. Continued westward A-type subduction (Whalen et al., 1987) during the Early Jurassic resulted in accretion of terranes to the ancient continental margin. However the boundary between the allochthonous terranes of the Intermontane Belt and displaced North American strata has been difficult to resolve. The initial interpretation of the Teslin Zone was a suture that was thrust eastwards over the Cassiar Platform (Tempelman-Kluit, 1979). Subsequent re-interpretations include: a root zone for nappes and steeply dipping tectonites (Hansen, 1990; 1992a, b), a crustal-scale flower structure (Stevens, 1994); bivergent thrusting above a thrust detachment (Stevens and Erdmer, 1996), and a large-scale F_3 synform (de Keijzer et al., 1999, especially p. 481; deKeijzer and Williams, 1999). The latter interpretation suggests that the Teslin Zone is not a terrane boundary, and ancient continental crust may extend beneath the Teslin Zone tectonites.

Obduction of the Slide Mountain oceanic terrane occurred no later than 183 Ma (Gabrielse and Brookfield, 1988), which is close to the age determined for the Southwest Thirtymile pluton. Middle Jurassic plutonism is recorded from the accreted terranes in BC (Gabrielse, 1991, p. 601; Woodsworth et al., 1991, p. 504, 506), but is extremely rare in the continental margin (Armstrong, 1988; J.K. Mortensen, pers. comm., 1993).

The chemistry of the Northwest Thirtymile and Southwest Thirtymile stocks (Liverton and Alderton, 1994) and Sr_i of 0.7045 for the Southwest stock are consistent with juvenile magma. The source could have been either subducted oceanic crust or a mantle wedge above a subduction zone. The continental crustal component was minor.

The polarity of the subduction zone is deduced to have been eastward. Detrital zircons indicate that the siliciclastic sedimentary rocks of the Thirtymile Range have a western Canadian shield and northern Cordilleran miogeocline provenance (Ross and Harms, 1998); thus this area is effectively 'tied' to the continent. A west-facing arc could not have been built upon these sediments because they would have been dragged into the subduction zone. Instead undeformed Jurassic plutons cut the fabric of the Thirtymile Range metasedimentary rocks and therefore place an upper age limit on the penetrative deformation.

3. Angular dispersion of regional structures

The orientation of the mesoscopic-scale linear fabric is consistent with its having been generated by oblique obduction. In transpressive regimes the orientation of fold axes marginal to the main fault is at 45° to that structure, and a simple shear model for deformation has been suggested (Jamison, 1991). This is in contrast to purely convergent terranes (pure shear), which produce fold axes parallel to the fault. The analogue modelling of transpression by Odonne and Vialon (1983) produced similar results. During simple shear, folds are progressively developed and their axes become rotated parallel to the fault. Fold axes are curved, although at greater distances from the fault they remain at the initial 40-45° angle to its strike. Furthermore, axial planes of folds become progressively flatter away from the fault; in cross-sections they resemble a fan or flower structure.

Lineations are similarly affected. Escher and Watterson (1974) proposed that L-S tectonite fabrics in which the planar element dips at a low angle away from the foreland, and where the stretching element is transverse to the boundary of the belt, originate by simple shear deformation. Early formed folds would be rotated so that their axes approximate the original stretching lineation. The C-S fabrics observed in the Thirtymile Range are considered to indicate layer-parallel extension in sheared lithologic units. Mechanisms of such foliation-boudinage formation as a layer-parallel extension phenomenon have been addressed by Platt and Vissers (1980): extension along the foliation results in brittle failure (shear band development) and, where the deformation is non-coaxial, forms an asymmetric boudinage. Furthermore, the cleavage orientation does not appear to be related directly to axes of finite strain. The structural mechanism described above can produce the eastward vergence observed in the central Thirtymile Range.

The pre-183 Ma deformation is deduced from Rb/Sr geochronology. At least two possibilities exist. The deformation may represent the effect of oblique obduction of the Dorsey Terrane onto the North American continent immediately before intrusion of the hornblende-rich plutons, or it could be much older, such as the Mississippian-aged fabrics determined for parts of the Yukon-Tanana Terrane (J.K. Mortensen, pers. comm., 1992; Colpron and Reinecke, 2000).

The chemical and Sr isotopic evidence of the mid-Jurassic calc-alkaline plutons indicates subduction. Oceanic crust may have been subducted or underplated ('wedging'; Price, 1986), or the melting of thickened crust produced juvenile magma. Could subduction in the Jurassic have had a short-lived westward polarity, consuming oceanic crust developed in a late Carboniferous to early Permian rift basin? In contrast, the Sr-isotope initial ratios and chemistry of the Seagull-Thirtymile plutons is entirely consistent with generation in a thickened continental crust. It bears much similarity to the Cassiar Batholith (Driver et al., 2000). Cretaceous magmatism, although widespread, maintained low upper crustal temperatures in the Thirtymile Range because it did not reset the Sr isotopic system of the Jurassic Southwest Thirtymile pluton.

CONCLUSIONS

The tectonic history of the western assemblages of the 'Dorsey Terrane' is open to discussion. Detrital zircon geochronology indicates that the siliciclastic strata in the Thirtymile Range were derived from the continental margin (Ross and Harms, 1998). Penetrative deformation of that part of the succession is constrained at no younger than 181 Ma by the geochronology presented here. The mid-Jurassic magmas have a distinct subduction-related chemistry. Magma generation during eastward-directed subduction is most likely.

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Age and setting of dinosaur trackways, Ross River area, Yukon Territory (105F/15)

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ABSTRACT

Chert-bearing clastic strata are a common component of Jurassic and younger terrestrial sequences in the Yukon. The discovery of dinosaur trackways in a small inlier of chert-bearing clastic strata within the Tintina Trench, 3 km west of Ross River, led to reevaluation of its sedimentary framework and previously assumed Eocene age. A mid-Cretaceous (middle Albian to early Cenomanian) age is inferred from a miospore assemblage that includes the angiosperms *Cupuliferoidaepollenites minimus, Retitricolpites prosimilis, Retitricolpites virgeus* and *Senectotetradites amiantopollis.* The trackways are preserved on at least three levels within the >427 m of section exposed along and north of the Robert Campbell Highway. They occur in splay deposits associated with small, sandy meandering rivers that flowed parallel to the direction of the Tintina Trench. Most trackways appear to be heading towards the southeast, suggesting systematic migration patterns during the wet season. Conglomeratic strata were deposited by wandering gravel-bed rivers that also flowed parallel to the trench. Individual channels were up to 12 m deep and more than 50 m wide.

RÉSUMÉ

On trouve souvent des strates clastiques cherteuses dans les séquences terrestres d'âge Jurassique et plus jeunes du Yukon. Des pistes de dinosaures ont été découvertes dans une petite enclave de strates clastiques cherteuses, dans le fossé de Tintina, à 3 km à l'ouest de Ross River, ce qui nous a amenés à réévaluer la structure sédimentaire de cette séquence, ainsi que son âge auparavant présumé de l'Éocène. Nous déduisons d'un assemblage de miospores, dont les angiospermes *Cupuliferoidaepollenites minimus, Retitricolpites prosimilis, Retitricolpites virgeus* et *Senectotetradites amiantopollis,* qu'elles datent du Crétacé moyen (entre l'Albien moyen et le Cénomanien précoce). Les pistes sont identifiables sur au moins trois niveaux de la section de plus de 427 m qui affleure en bordure, et au nord de la route Robert Campbell. Elles se trouvent dans des sédiments plats et divergents associés à de petits cours d'eau méandriques sablonneux qui s'écoulaient parallèlement à l'axe du fossé de Tintina. La plupart des pistes semblent se diriger vers le sud-est, indiquant des mouvements de migration systématiques durant la saison humide. Des strates conglomératiques furent aussi déposées par de petits cours d'eau sinueux au lit graveleux qui s'écoulaient aussi parallèlement à l'axe du fossé. Les chenaux atteignaient 12 m de profond et plus de 50 m de large chacun.

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INTRODUCTION

Conglomerates and sandstones containing abundant chert and chert look-alikes are a common component of Jurassic and younger terrestrial sequences in the Yukon Territory. They include the Upper Jurassic(?) to Lower Cretaceous strata of the Tantalus Formation in the Whitehorse Trough (Long, 1982a,b, 1983, 1986; Bremner, 1988; Hart and Radloff, 1990; Allen, 1999; Allen and Weston, 2000) and Indian River area (Lowey, 1982, 1983a; Lowey and Hills, 1988); Upper Cretaceous strata in the Bonnet Plume basin (Norris and Hopkins, 1977; Long, 1978, 1986), the Eagle Plain Formation (Moorehouse, 1966; Mountjoy, 1967), and Moose Channel Formation (Young, 1975); and Tertiary strata in the Bonnet Plume basin (Long, 1978, 1986), Reindeer Formation (Mountjoy, 1967, Young, 1975, Norris, 1981) and along the trend of the Tintina fault zone near Dawson, Ross River and Watson Lake (Hughes and Long, 1980; Long, 1981; Long et al., 1990). The petrographic similarity of some of these sequences along the trend of the Tintina fault zone is shown in Figure 1. Most of the sandstones are sedlitharenites (Fig. 1a, c), containing abundant mudstone, carbonate and sandstone rock fragments, subordinate granitic rock fragments and only minor chert. The chert-like appearance of these sequences appears to be related to the abundance of fine-grained sedimentary rock fragments rather than true chert. Quartz types do not appear to be useful in distinguishing these strata (Fig. 1b).

Chert-bearing clastic strata located in a fault-bounded block within the Tintina Trench, beginning 2 km west of the townsite of Ross River (Fig. 2), were originally thought to be part of an 800- to 1100-m-thick Tertiary sequence of conglomerate and mudstone, with minor sandstone

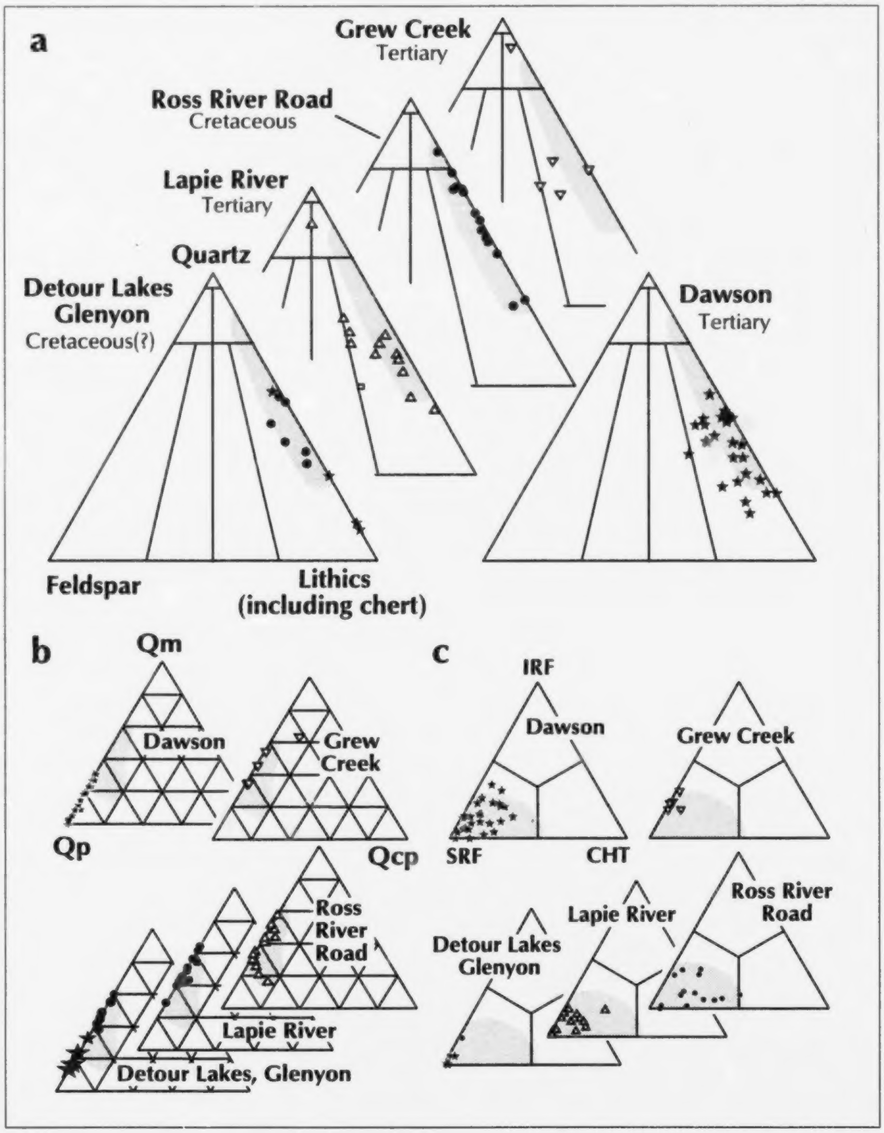


Figure 1. (a) Petrography of framework grains in samples from localities along the Tintina Trench (minimum 700 framework grains per thin section); (b) Quartz grain-types (Qp = polycrystalline grains - fine; Qcp = coarse polycrystalline grains; Qm = monocrystalline quartz. Strained quartz was not present in significant amounts); (c) Petrography of rock fragments (IRF = igneous rock fragments; SRF = sedimentary rock fragments; CHT = Chert); Petrographic field of strata in the Ross River Road block is shaded.

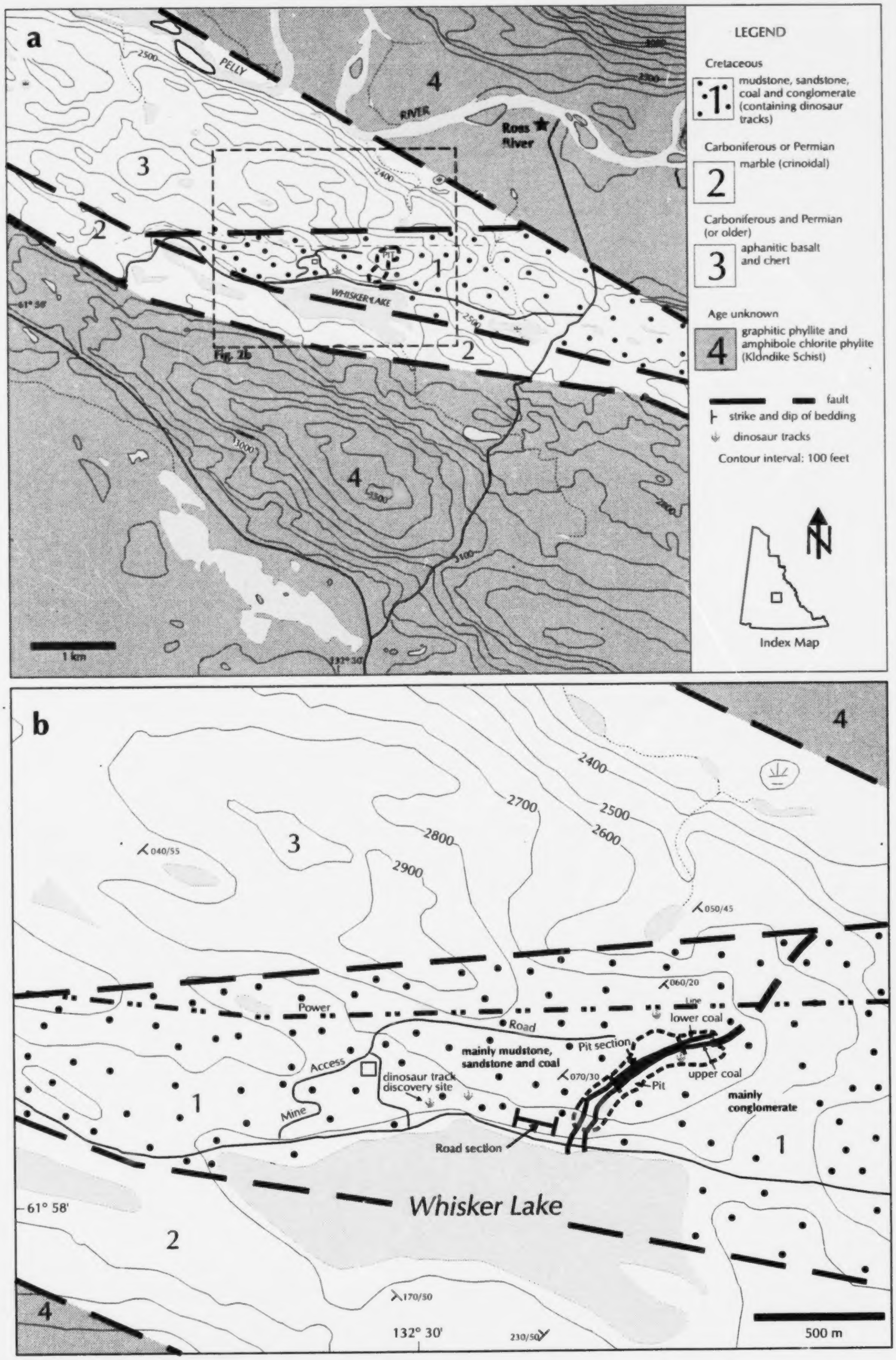

a
LEGEND
Cretaceous
1
mudstone, sandstone, coal and conglomerate (containing dinosaur tracks)
Carboniferous or Permian
2
marble (crinoidal)
Carboniferous and Permian (or older)
3
aphanitic basalt and chert
Age unknown
4
graphitic phyllite and amphibole chlorite phylite (Klondike Schist)
fault
strike and dip of bedding
dinosaur tracks
Contour interval: 100 feet
Index Map
PELLY
RIVER
Ross River
WHISKER LAKE
Pit
Fig. 2b
61° 58'
132° 30'
1 km
2500
2400
3000
3300
b
2400
2700
2500
2800
2600
2900
040/55
050/45
060/20
070/30
170/50
230/50
Power
Line
Road
Access
Mine
lower coal
upper coal
Pit section
Pit
mainly mudstone, sandstone and coal
dinosaur track discovery site
mainly conglomerate
Road section
Whisker Lake
61° 58'
132° 30'
500 m

Figure 2. *(a) Geological map of the area near Ross River (modified from Tempelman-Kluit, 1977; Hughes and Long, 1980; Pigage, 1988). (b) Detailed geological map.*

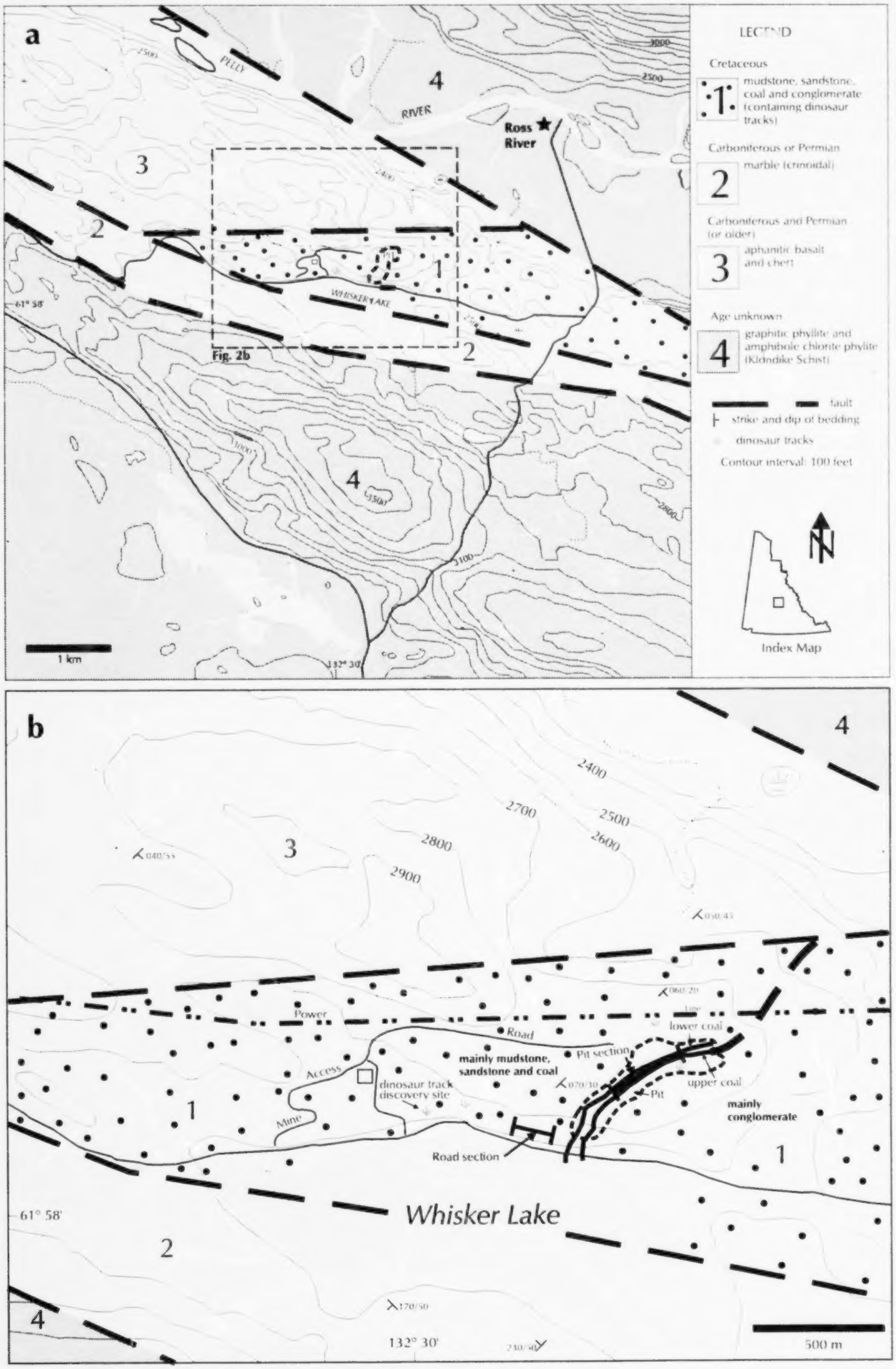
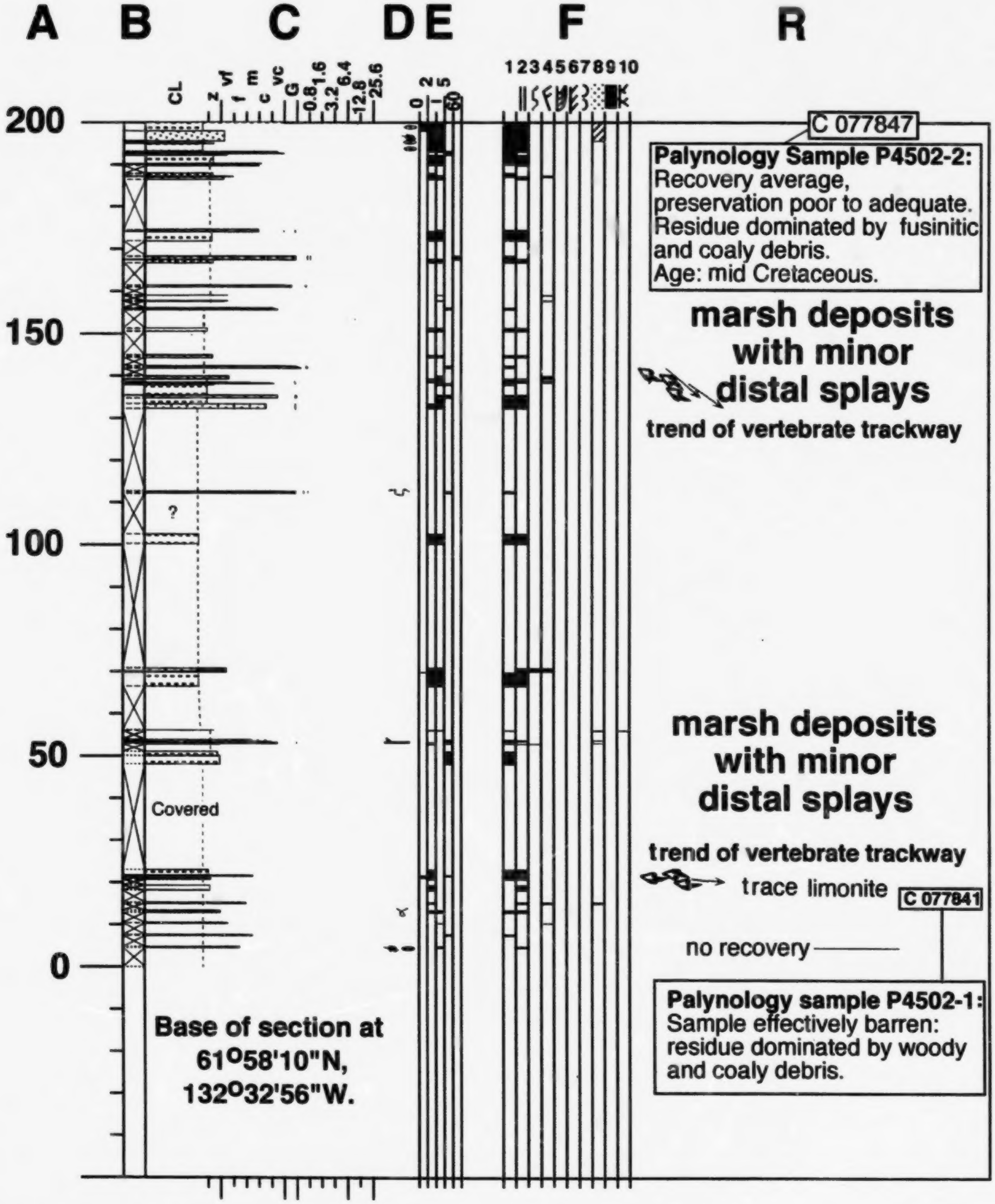

a
PELLY
RIVER
Ross River
4
3
2
1
Pit
WHISKER LAKE
Fig. 2b
61° 58'
132° 30'
1 km
LEGEND
Cretaceous
1 mudstone, sandstone, coal and conglomerate (containing dinosaur tracks)
Carboniferous or Permian
2 marble (crinoidal)
Carboniferous and Permian (or older)
3 aphanitic basalt and chert
Age unknown
4 graphitic phyllite and amphibole chlorite phyllite (Klondike Schist)
fault
strike and dip of bedding
dinosaur tracks
Contour interval: 100 feet
N
Index Map
b
2400
2500
2600
2700
2800
2900
040/55
030/45
060/20
070/30
170/50
210/50
Power
Road
Access
Mine
dinosaur track discovery site
mainly mudstone, sandstone and coal
Pit section
lower coal
upper coal
Pit
mainly conglomerate
Road section
Whisker Lake
61° 58'
132° 30'
500 m

Figure 2. *(a) Geological map of the area near Ross River (modified from Tempelman-Kluit, 1977; Hughes and Long, 1980; Pigage, 1988). (b) Detailed geological map.*


A
B
C
D
E
F
R
200
150
100
50
0
CL
z
vf
f
m
c
vc
G
0.8
1.6
3.2
6.4
12.8
25.6
0
2
1
5
60
12345678910
?
Covered
C 077847
C 077841
marsh deposits with minor distal splays
trend of vertebrate trackway
marsh deposits with minor distal splays
trend of vertebrate trackway
trace limonite
no recovery

Palynology Sample P4502-2: Recovery average, preservation poor to adequate. Residue dominated by fusinitic and coaly debris. Age: mid Cretaceous.

Palynology sample P4502-1: Sample effectively barren: residue dominated by woody and coaly debris.

Base of section at 61°58'10"N, 132°32'56"W.

Figure 3. *Stratigraphy of the Ross River block, based on exposures adjacent to the Robert Campbell Highway, at Whisker Lake. A = elevation above base of section in metres. B = contacts, solid line = sharp, dashed line = transitional, dotted line = not seen, cross indicates no exposure. C = grain size: CL = claystone, M = mudstone, S = sandstone, z = siltstone, vf (very fine), f (fine), m (medium), c (coarse), vc (very coarse) = sandstone, G = granule conglomerate, number = grain size*

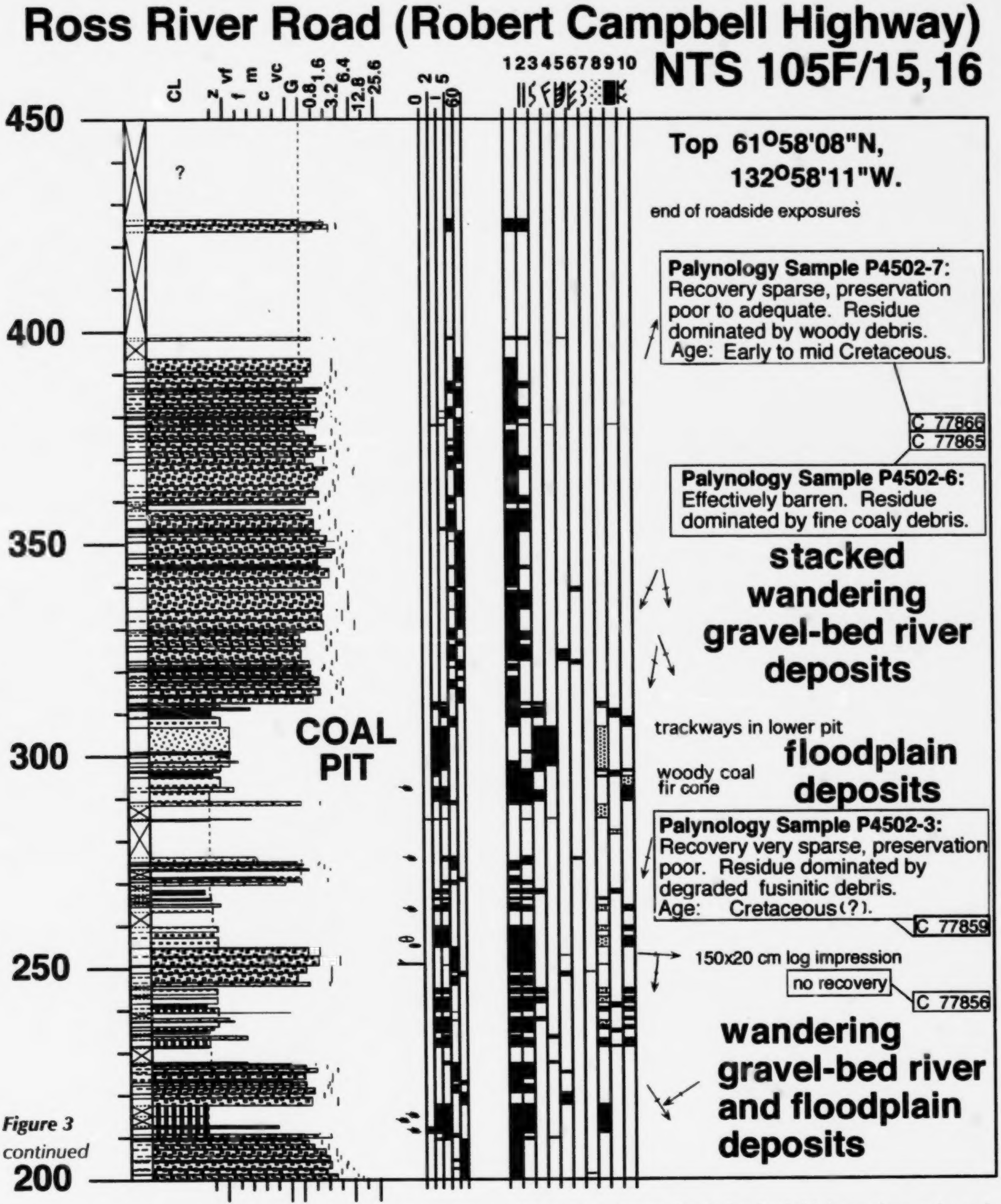


Figure 3 continued

in cm., p = pebble, g = granule. D = minor structures (concretions, plant leaves, logs). E = bed thickness (range in cm). F = sedimentary structures: 1 = appears massive; 2 = plane bedded; 3 = wavy bedded; 4, r = ripple cross-laminated; 5, t = trough cross-stratified; 6 = planar cross-stratified; h = horizontally laminated; w = wavy laminated; 7 = mudstone intraclasts; 8 = dispersed organic material; 9 = coal; 10 = traces of fossil plant roots; R = remarks. Arrows indicate paleoflow directions.

and coal (Kindle, 1946; Wheeler, et al., 1960; Milner and Craig, 1973; Tempelman-Kluit, 1977; Hughes and Long, 1980; Long, 1981; Long et al., 1990). While miospores in this block were found to be very poorly preserved due to thermal degradation, a Tertiary age was assumed because of the similarity of this strata to clastics in a second block at Lapie River, 7 km west of the Ross River townsite where Hopkins (1979) recovered a better preserved assemblage of palynomorphs. These included *Alnus,* which was taken as suggestive of an Early Eocence to late Middle Eocene age. A stratigraphic gap of about 200 m was estimated between the two sections based on vitrinite reflectance gradients (Hughes and Long, 1980). The subsequent discovery of dinosaur tracks in the Ross River block by Roland Gangloff and Kevin May of the University of Alaska (Pedersen, 1999; Gangloff et al., 2000) indicated that the original age assignment was in error. In order to determine the geological context of these tracks, the section was re-examined and re-sampled. Palynological samples collected in 1978 were re-processed and re-examined. Results of this study are outlined below.

GEOLOGICAL SETTING

The Ross River area is underlain by the Yukon-Tanana Terrane, an assemblage of polydeformed metamorphic rocks that is thought to be Paleozoic in age (Mortensen, 1990, 1992, 1996). According to Mortensen (1992), the Yukon-Tanana Terrane consists mainly of pelitic to quartzofeldspathic metasedimentary schist and gneiss with minor amounts of marble and mafic to felsic metavolcanic and metaplutonic rocks. It was juxtaposed with other terranes (i.e., Slide Mountain) by regional-scale thrust faulting in early Mesozoic time and structurally overlies the ancient continental margin of North America (Mortensen, 1990). The Yukon-Tanana Terrane is unconformably overlain by post-accretionary, mid- to Late Cretaceous sedimentary and volcanic rocks (Mortensen, 1996). Both the pre-accretionary and post-accretionary rocks are offset by at least 450 km of dextral movement along the Tintina fault zone, the displacement of which is thought to have occurred in the Late Cretaceous and Early Tertiary (Roddick, 1967; Long, 1981). The exact position of the Tintina fault zone in the area is uncertain. Tempelman-Kluit (1977) placed it about 2 km southwest of the rectangular area delineated on Figure 2, while magnetotelluric studies by Ledo, et al. (2000) indicate that the main crustal discontinuity may be east of the Ross River fault-bounded block. Ledo et al. (2000) also recognize a second crustal discontinuity further to the west, which coincides with the St. Cyr fault.

Tempelman-Kluit (1977) provides the most complete coverage of the bedrock geology in the Ross River area. The map by Roddick (1960) is dated but provides useful descriptive notes. Hughes and Long (1980) and Long et al. (1990) outline the geology and coal resource potential of the sedimentary rocks in the Ross River area, and a detailed map (1:2000 scale) of the area mined is included in the drilling report by Pigage (1988). The surficial geology has been discussed by Plouffe and Jackson (1995).

NEW OBSERVATIONS

Strata in the Ross River block consist of at least 427 m of mudstone, conglomerate and sandstone, with minor coal (Fig. 3). Most strata dip 20-30° to the southwest.

MUDSTONES AND COAL

Mudrocks dominate the lower 200 m of the section; they are predominantly dark grey to dark greenish grey claystones with minor siltstone. Most appear massive with a pseudo-brecciated appearance (cf. Fig. 4, lower unit), or exhibit faint horizontal stratification. Traces of plant roots are rare below the 200 m level and common between the 200 and 310 m levels (Fig. 3). Black, organic-rich mudrocks are developed locally in the lower 200 m of the section, but are more common in association with coals in the 200 to 310 m interval.

Coal forms a small but significant part of the sequence. Five seams of bituminous coal were recognized in the area prior to mining (Hughes and Long, 1980). Open-pit mining of the recessive interval below the upper conglomerate has exposed two of these seams from which Nadahini Mining Corporation extracted about 50,000 tonnes of coal (Pigage, 1988; Hunt, 1994). The lower of the two seams is a dull woody coal, 1.7 to 1.8 m thick, which rests on a 40-cm-unit of massive (pseudo-brecciated) organic-rich mudstone with abundant fossil plant roots. The upper seam is a dull woody coal, 1.5 to 1.8 m thick, which rests on an organic-rich mudstone, and is locally interbedded with wavy and ripple cross-laminated, fine to very fine sandstones. Further near-surface coal deposits may be present along strike to the northeast.

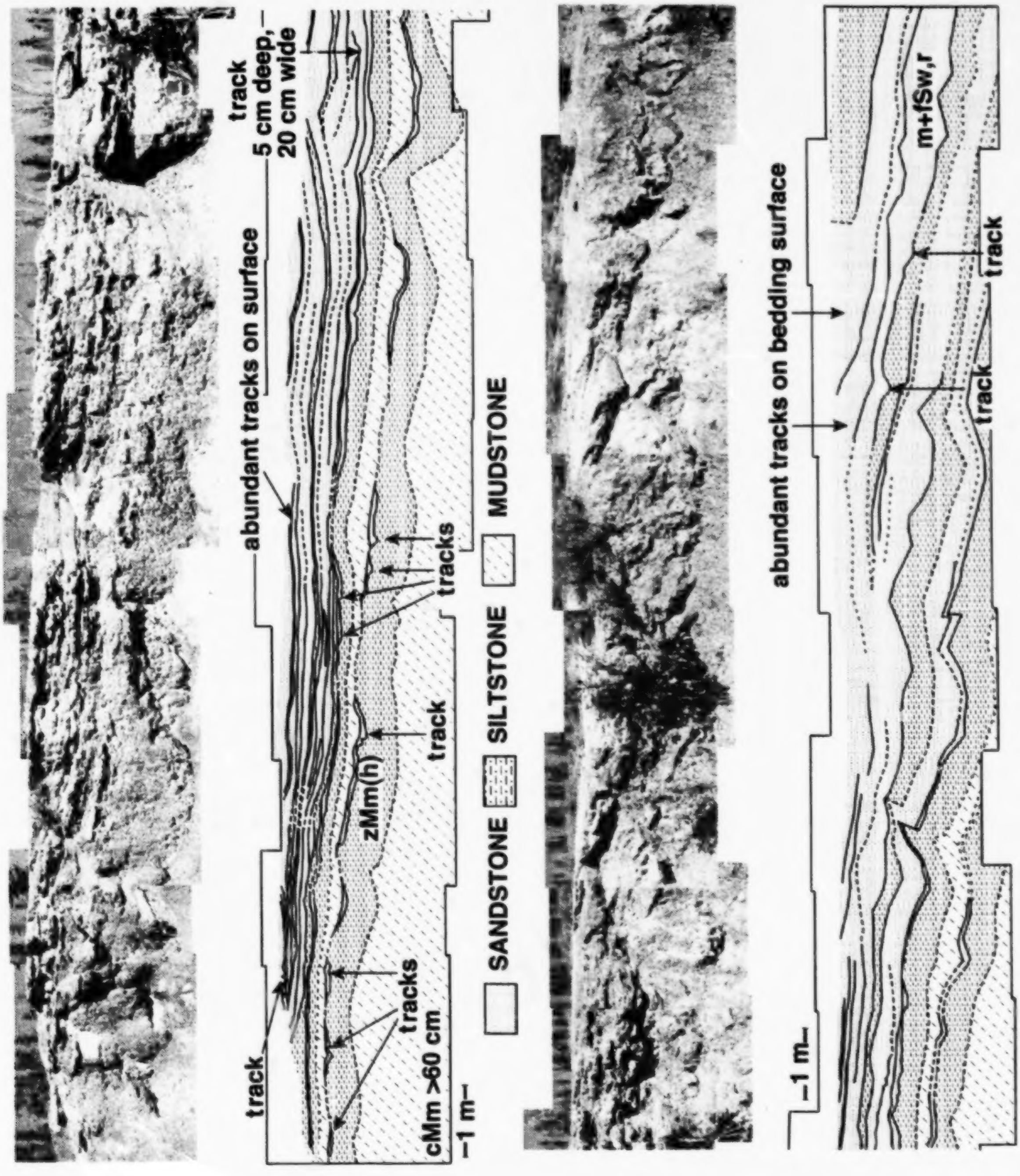

track
abundant tracks on surface
track
5 cm deep,
20 cm wide
tracks
cMm >60 cm
zMm(h)
track
tracks
~1 m~
SANDSTONE
SILTSTONE
MUDSTONE
abundant tracks on bedding surface
m+fSw,r
track
track
1 m

Figure 4. *Exposure of track-bearing mudstone and very fine- to medium-grained sandstones of probable splay origin, adjacent to Robert Campbell Highway north of Whisker Lake. See Figure 3 for explanation of abbreviations.*

SANDSTONES

Sandstones form a minor part of the sequence. All have a speckled (salt-and-pepper) texture due to the abundance of resistant lithic clasts (Fig. 1). They occur as thin sets (5-50 cm) of planar-laminated, wavy and ripple cross-laminated, silty fine- and very fine-grained sandstones; thin to thick co-sets (0.1-7 m) wavy and ripple cross-laminated, fine- to medium-grained sandstones; and minor massive and planar-laminated, poorly sorted to moderately poorly sorted, medium to granular, very coarse-grained sandstones in sets 0.15-1.3 m thick. Ripple cross-laminated medium- to very coarse-grained sandstones are found as thin layers within conglomeratic parts of the sequence. Finer grained sandstones are locally interbedded with siltstones and organic-rich mudstones, and may contain local (early) nodular siderite concretions (Fig. 5a). Large-scale bedforms include shallow scour surfaces and channels (Fig. 5b,c, 6). Epsilon cross-stratification is developed locally (Fig 5d, 6).

CONGLOMERATE

Conglomerates are conspicuous in the upper part of the sequence. They occur in stacked sequences a few metres to more than 90 m thick (Fig. 3) and as minor components of small channels in finer grained parts of the section (Fig. 7a). They consist predominantly of thick beds (5 cm - 5.5 m) of yellow-brown-weathering, framework-supported, moderately well sorted, small- to large-pebble conglomerate: sedlithrudite (Fig. 8). Clasts are typically rounded to subrounded, with a maximum observed clast size of 9 cm. In the section along the Robert Campbell Highway, most of the conglomerates appear to be massive

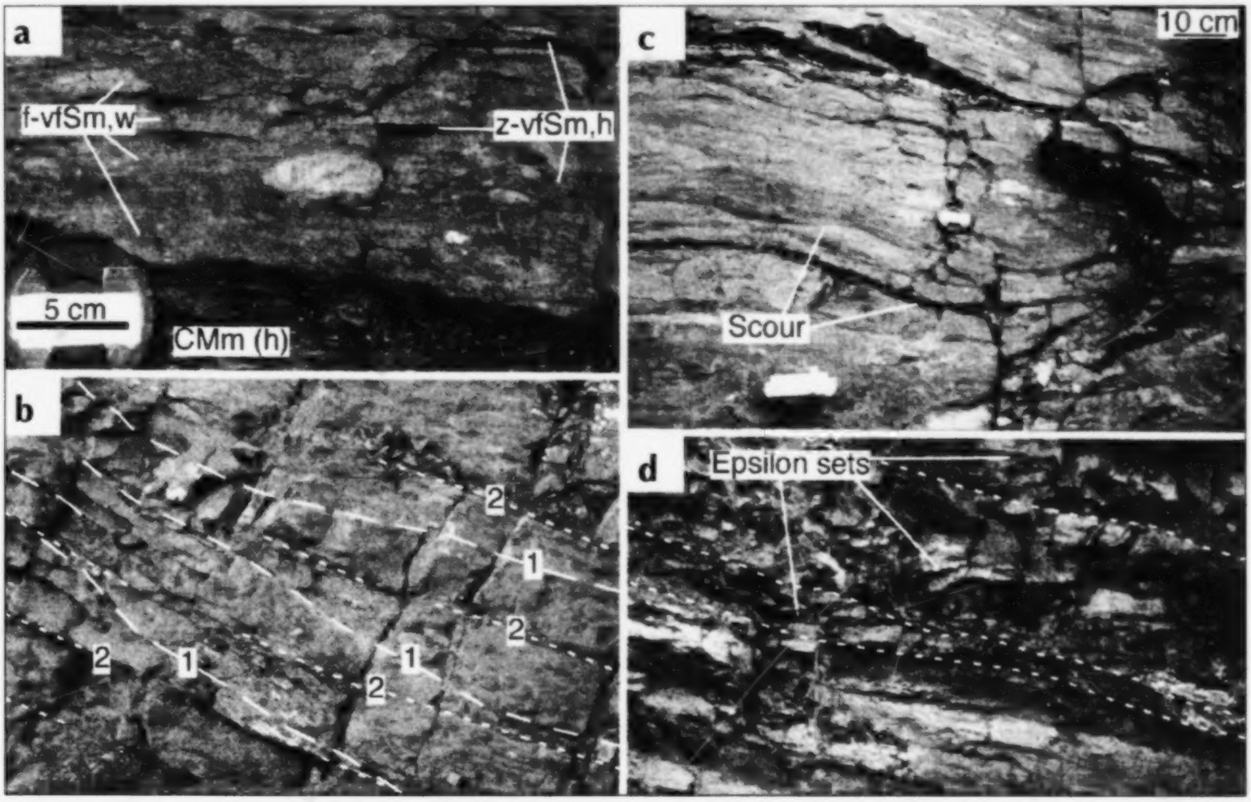


Figure 5. *Fine- to medium-grained sandstones: (a) Massive to wavy bedded fine- to very fine-grained sandstone with siderite nodules (in upper coal pit); (b) shallowly inclined co-sets of fine- to very fine-grained wavy laminated sandstone of levee-splay origin (upper coal pit); (c) local scour surfaces in fine- to very fine-grained flat to wavy laminated sandstones of levee-splay origin (upper coal pit); and (d) well developed epsilon cross-stratification, marked by alternating beds of fine- to very fine-grained sandstone and siltstone (below upper coal seam in upper pit). See Figure 3 caption for explanation of abbreviations.*

or planar-laminated (Fig. 7b). In the coal pit, this is seen to be an illusion as most of the strata are characterized by large-scale (1-5.5 m) planar and trough cross-stratification (Fig. 7c), with grouped sets occupying broad channels up to 12 m deep (Figs. 7d, 9). An unusual scalloped erosional contact was noted at the base of one conglomeratic unit at the north end of the upper pit (Fig. 7e).

DEPOSITIONAL FACIES

Clay-mudstones in the Ross River sequence are here interpreted as the products of deposition in overbank marsh and pond environments. Well developed planar lamination, characteristic of lake deposits was not seen. The grey colour is related to moderate dispersed organic content. The predominance of grey, rather than black mudrocks suggests marsh environments with the water table at or near the surface during part of the year. The brecciated appearance of many of the clay-mudstones (Fig. 4: lower unit) is due to the presence of numerous closely spaced, intersecting curved fracture surfaces. These slickensides are typically associated with a fluctuating water table (Try et al., 1984). In dry periods, the soil shrank and cracked, to swell again in wet periods. Rubbing of adjacent soil crumbs and blocks during repeated wetting and drying led to the production of grooved and polished surfaces, now represented by the slickensides (Donahue, et al., 1958; Fitzpatrick, 1980; Nadon, 1993). Siltstones are typically associated with both wavy to ripple cross-laminated sandstones and are interpreted as distal levee deposits. Organic-rich mudstones and coals were deposited in marsh and swamp environments, away from the main fluvial channels.

Finer-grained sandstones appear to have been deposited as overbank levee and splay deposits. The architecture (geometry) of some track-bearing splay deposits is shown

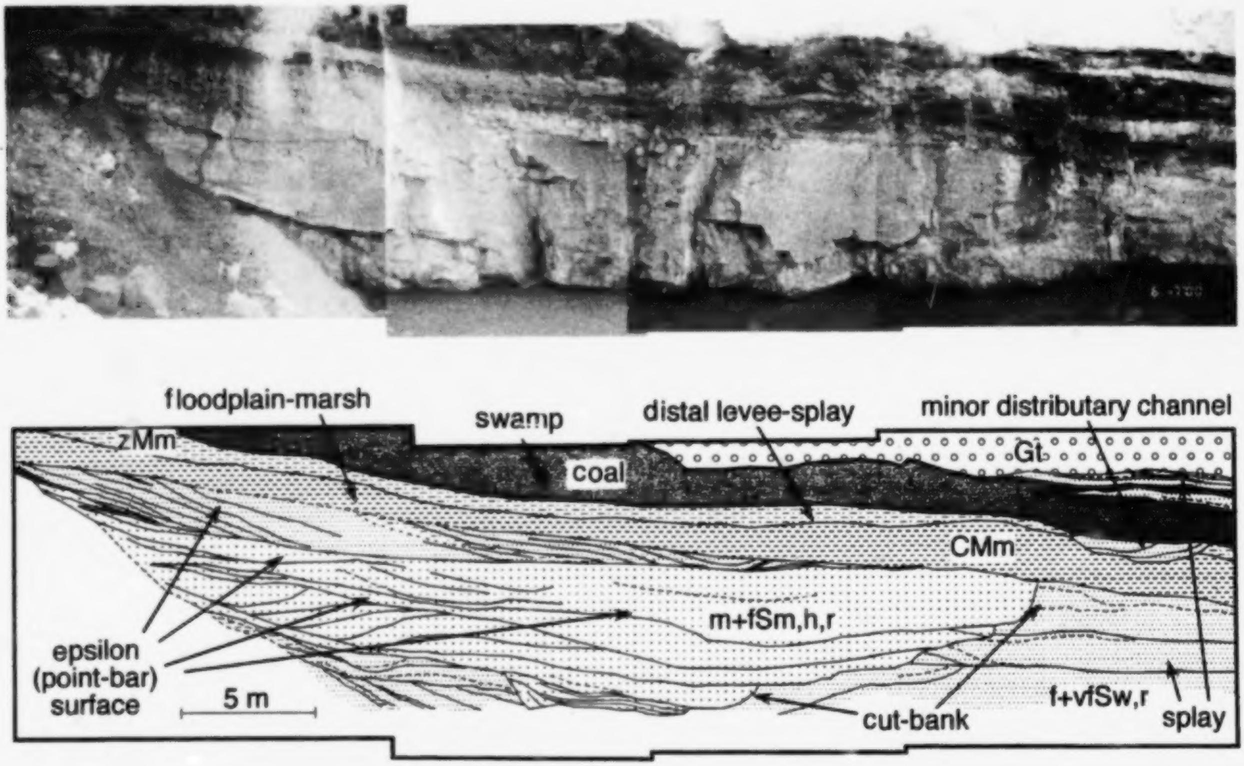


Figure 6. High-constructive (stable) channel deposit, with stacked epsilon cross-stratification. Note minor distributary channel deposit at base of upper coal seam, and splay deposits at the top of the coal seam (lower pit). See Figure 3 caption for explanation of abbreviations. Patterns as in Figure 9.

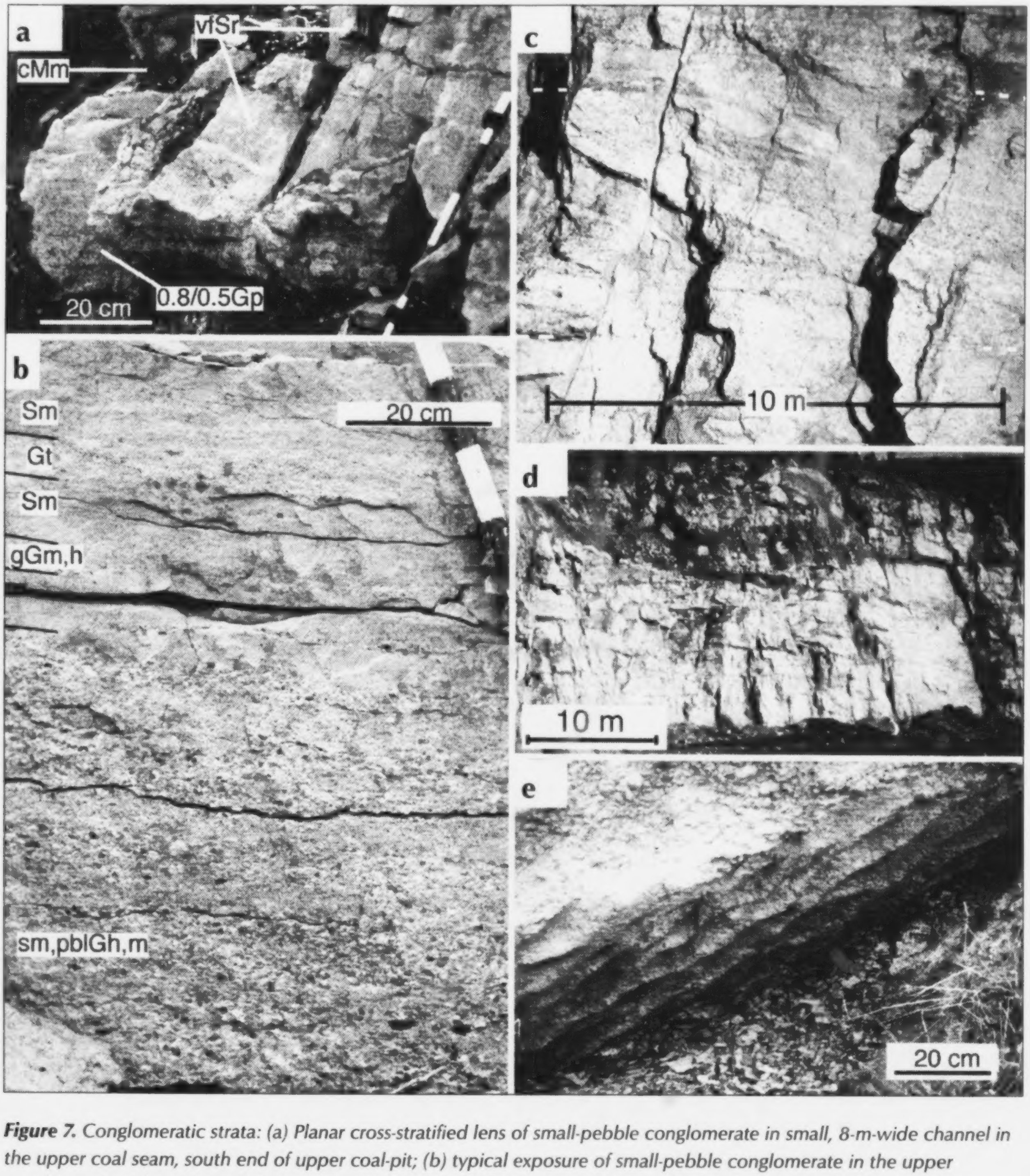


Figure 7. *Conglomeratic strata: (a) Planar cross-stratified lens of small-pebble conglomerate in small, 8-m-wide channel in the upper coal seam, south end of upper coal-pit; (b) typical exposure of small-pebble conglomerate in the upper conglomerate adjacent to the Robert Campbell Highway; (c) a 5.5-m-thick composite planar cross-stratified small- to medium-pebble conglomerate (dashed lines indicate set boundaries); (d) large-scale channel (12 m thick), with local organic-rich mudstone and planar and trough cross-stratified conglomerate, upper coal-pit; and (e) scalloped surface at contact between medium pebble conglomerate and silty mudstone, north end of upper pit. See Figure 3 for explanation of abbreviations.*

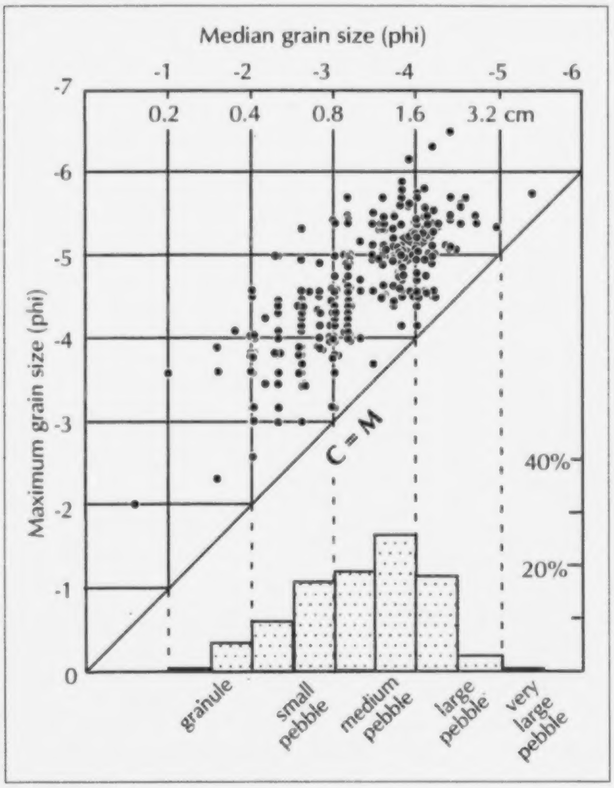


Figure 8. *Plot of maximum and median grain size of conglomeratic strata, based on 264 observations. Histogram at base shows a primary mode in the medium-pebble range.*

in Figure 4, which shows evidence of splay progradation over floodplain muds and silts. These appear to have supported lush vegetation as indicated by rare preserved plant roots, the crumbly, massive appearance of the mudstones due to soil-forming processes and root-bioturbation, and the occasional presence of well preserved plant leaves (Fig. 10f). Stacking of levee-splay sequences, as seen in the roadside section (Fig. 4) and in the coal-pit (Fig. 10) indicates an intimate association with stable stream channels. Local scour surfaces (Fig. 5c) may reflect scouring of levees during flood events. Low-angle inclined stratification (Fig. 5d) and epsilon cross-stratification may reflect lateral migration of crevasse channels or small streams. Lenticular sand bodies, such as those shown in Figures 6 and 7a, were deposited in low-gradient, high constructive stream systems, in which bank stability was probably maintained by dense plant growth (cf. Smith, 1976; Cairncross et al., 1988). The stacking of epsilon sets in these channel fills indicates that the streams had only a limited ability to erode channel walls. The paucity of channel deposits suggests that these were single channel systems, which changed position by avulsion, rather than being part of more extensive, multi-channeled anastomosed fluvial systems (cf. Nadon, 1993; Long, 2000).

Thicker conglomerate sequences in the Ross River fault-bounded block are all interpreted as products of deposition by wandering gravel-bed rivers (Forbes, 1983; Miall, 1996) rather than braided rivers. The roadside exposures appear to be dominated by massive to planar-laminated granule to small-pebble conglomerates, which would traditionally be interpreted as sheet-flood or longitudinal bar deposits of a high-gradient braided stream or alluvial fan (Long, 1981). The open-pit exposures show that the predominance of flat bedding is an artifact of the geometry of the roadside exposures. In the pit (Fig. 9), the sequence is dominated by large-scale (1 to 5.5 m) cross-stratification. These probably formed on side bars and in-channel bars in water depths of 2 to 12 m. Multiple scour and fill of older deposits has produced distinct channel deposits, some with complex sinusoidal geometry suggestive of deposition on point or side bars (Fig. 7d). This and the broad scatter of paleocurrents (Fig. 11), is suggestive of episodic migration of the river channels over the floodplain to produce extensive sheet-like bodies. Mudstones preserved in some of the channels reflect abandonment during avulsion. The section in Figure 9 is approximately normal to stream flow, so that the width of sedimentation units gives a minimum channel width of 30 to 80 m.

TRACKWAYS

To date, Gangloff et al. (2000) have documented over 150 individual tracks, produced by at least four taxa of dinosaurs in the Ross River block. Our investigation of the sedimentology of the area indicates that well preserved trackways occur on at least three levels within the sequence. These are all associated with fine-grained sandstones of overbank levee and splay origin, at the 20- and 140-m levels of the measured section (Fig. 3) in roadside exposures adjacent to the Robert Campbell Highway (Fig. 4), and at the 300-m level in the open-pit (Fig. 9) and in exposures along the power-line. Individual prints are between 20 and 50 cm long, and 15 to 35 cm wide and may include tracks of both herbivorous and carnivorous dinosaurs (Fig. 10). Where seen in cross-section, they resemble flute marks with relief of about

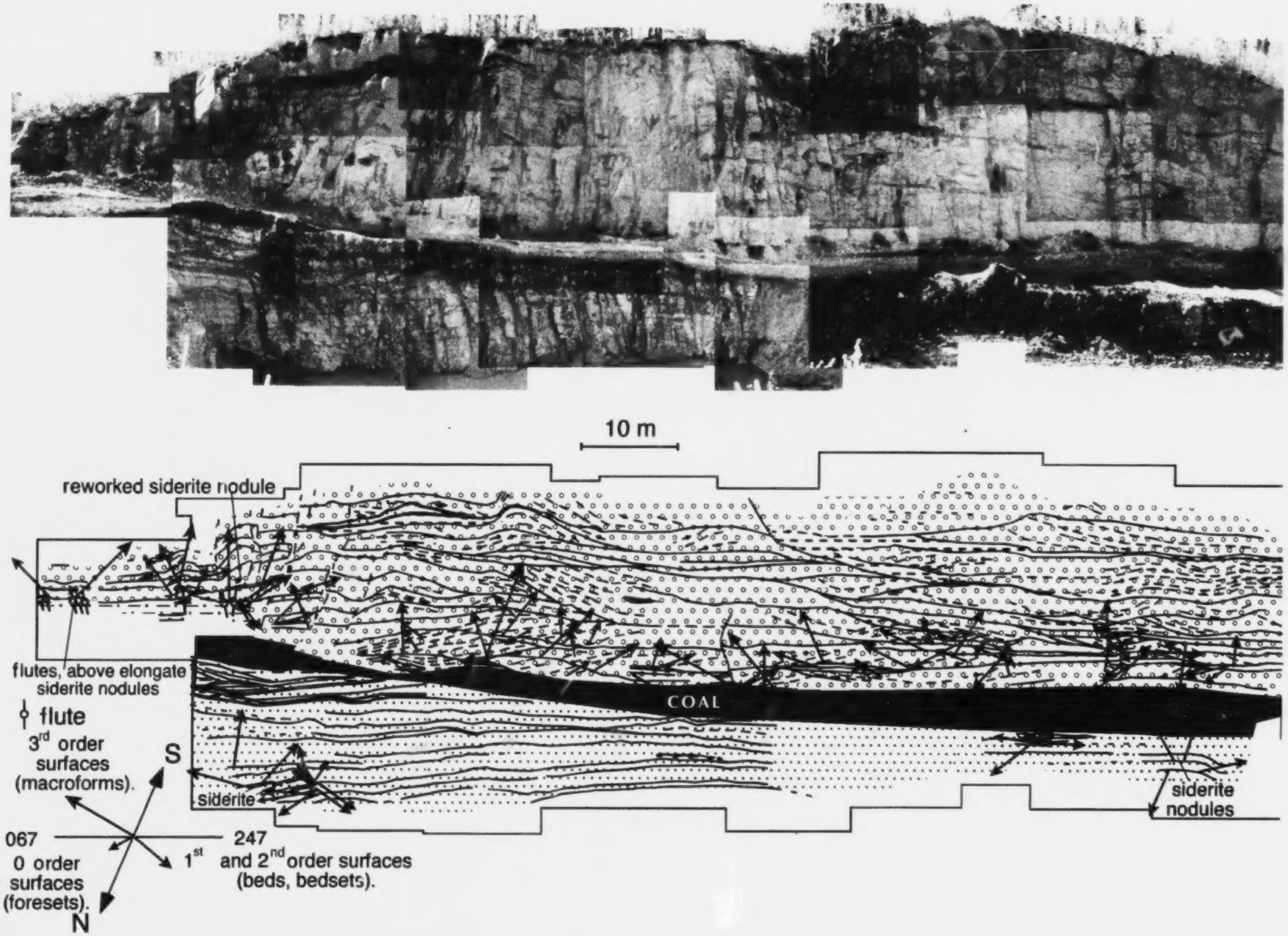

10 m
reworked siderite nodule
flutes, above elongate siderite nodules
flute
3rd order surfaces (macroforms).
067
0 order surfaces (foresets).
S
N
1st and 2nd order surfaces (beds, bedsets).
247
siderite
COAL
siderite nodules

Figure 9. Geometry and dip-corrected directional attributes of strata in the upper pit. Arrows directed above the horizontal indicate slopes dip away from the observer, those directed below the horizontal dip towards the observer (after correction for tectonic dip).

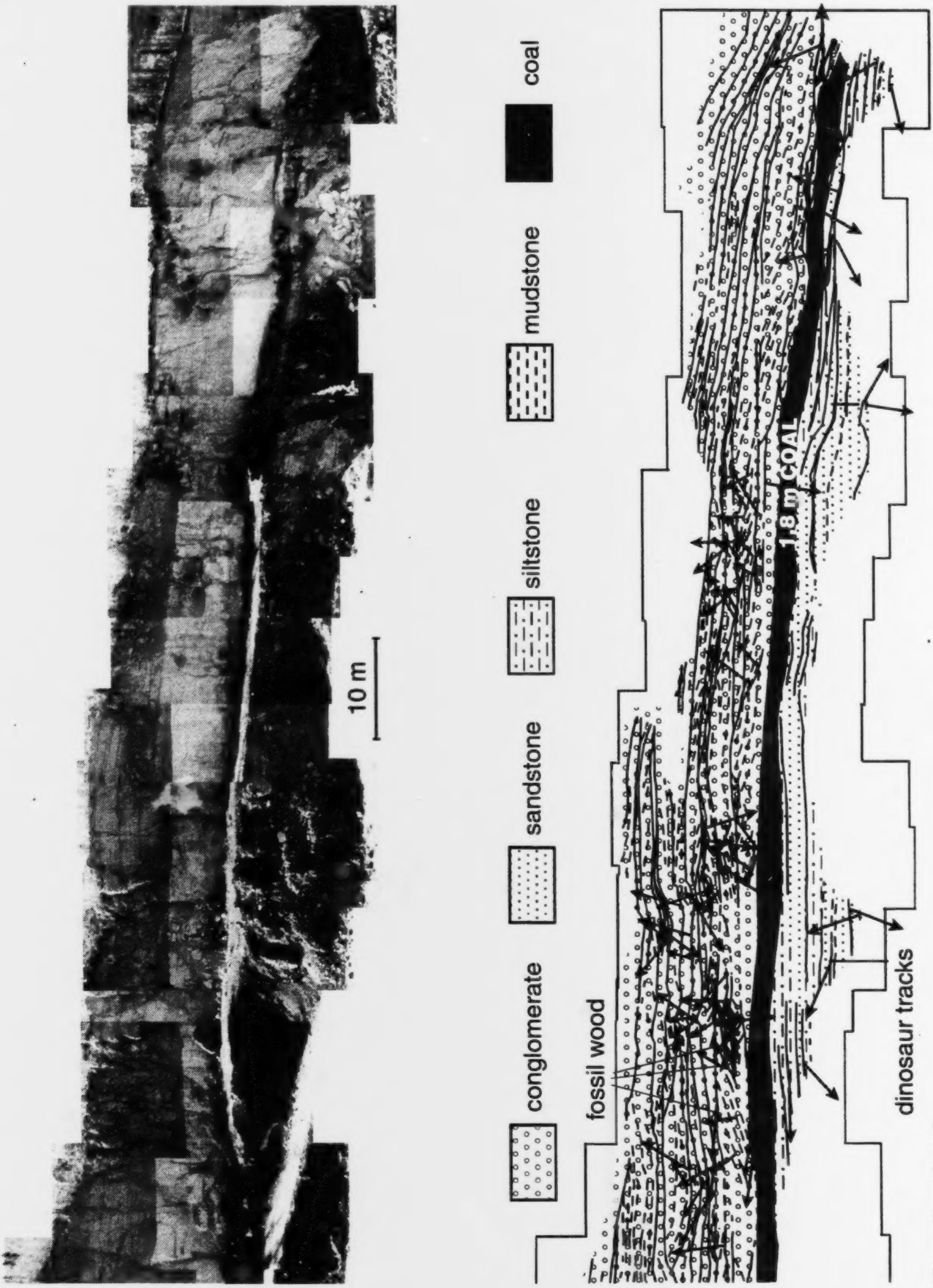

coal
mudstone
siltstone
sandstone
conglomerate
10 m
fossil wood
18 m COAL
dinosaur tracks

***Figure 9** continued.*

5 cm (Fig. 10e). Most of the tracks are filled with wave to ripple cross-laminated sandstone and only rarely with a thin film of mudstone. The trackways were probably produced and selectively preserved at times when the adjacent flood plains were submerged by seasonal floods. Also, the presence of (seasonal?) ponds is indicated by the degree of preservation of some of the plant fossils (Fig. 10f). Groups of herbivores may have walked on the submerged (distal) parts of sandy levees and splays associated with small high-constructive rivers, which flowed parallel to the axis of the modern Tintina Trench. A channel deposit of this type is exposed in the lower coal-pit (Fig. 6). The apparent consistent orientation of footprints suggests either seasonal migration during the

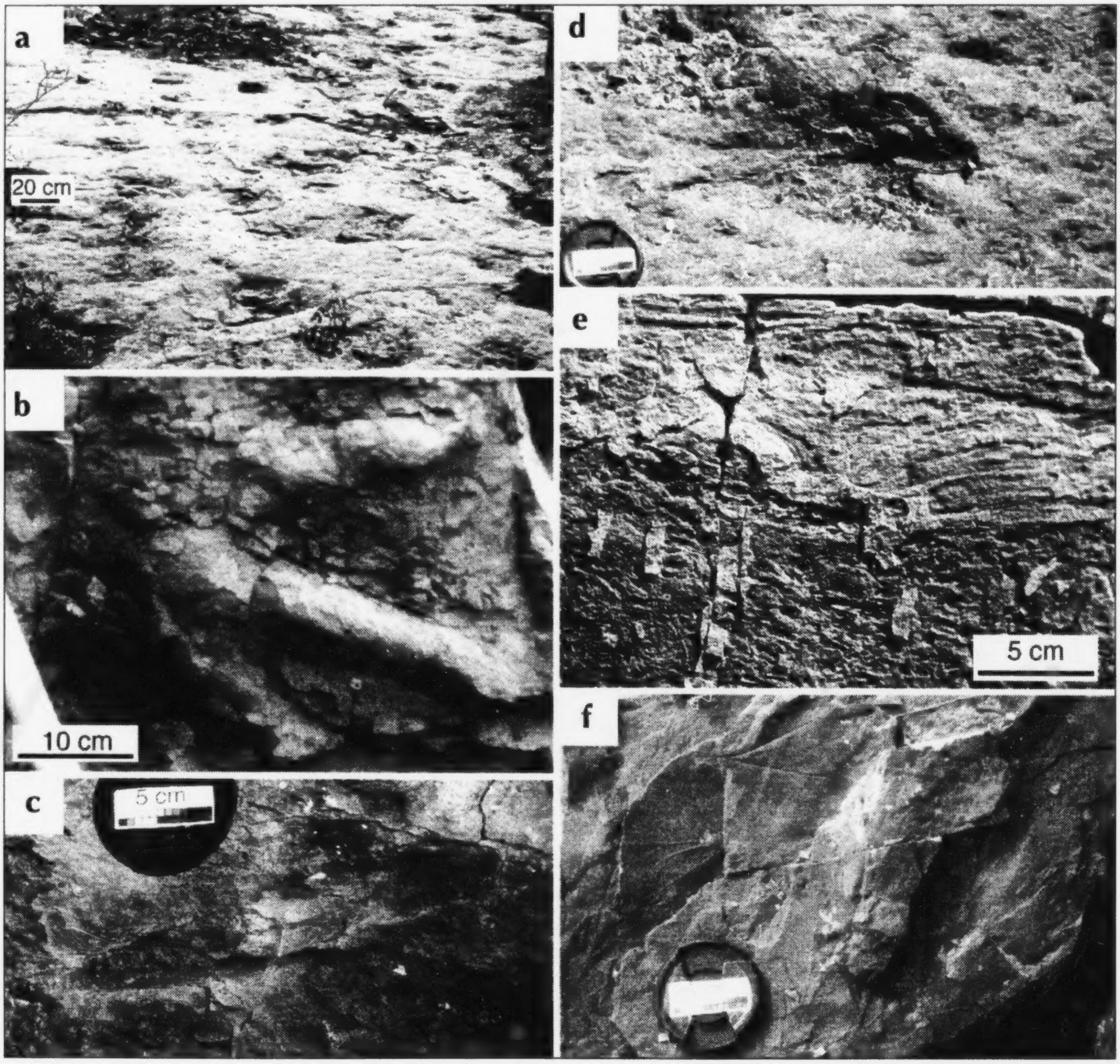


Figure 10. *Dinosaur trackways: (a) Trampled surface on top of section shown in Figure 4; (b) large prints from lower pit; (c) well preserved leaf impressions from siltstone interbeds in splay sandstone sequences, upper pit; (d) print from waste pile near upper pit; (e) print from trackway in (a); and (f) cross-section of track in upper pit with fill of ripple cross-stratified sandstone.*

wet season or easier transit along riverbanks during flood events. Nadon (1993) notes that wetlands associated with low-gradient fluvial systems were attractive areas for large herbivores, and that some species (including hadrosaurs) may have migrated to these areas during the wet season to escape large predators and lay eggs. Further observations are needed to test this hypothesis. The animals may have occupied the area during non-flood periods but left no lasting impressions. Vertebrate remains have yet to be recovered.

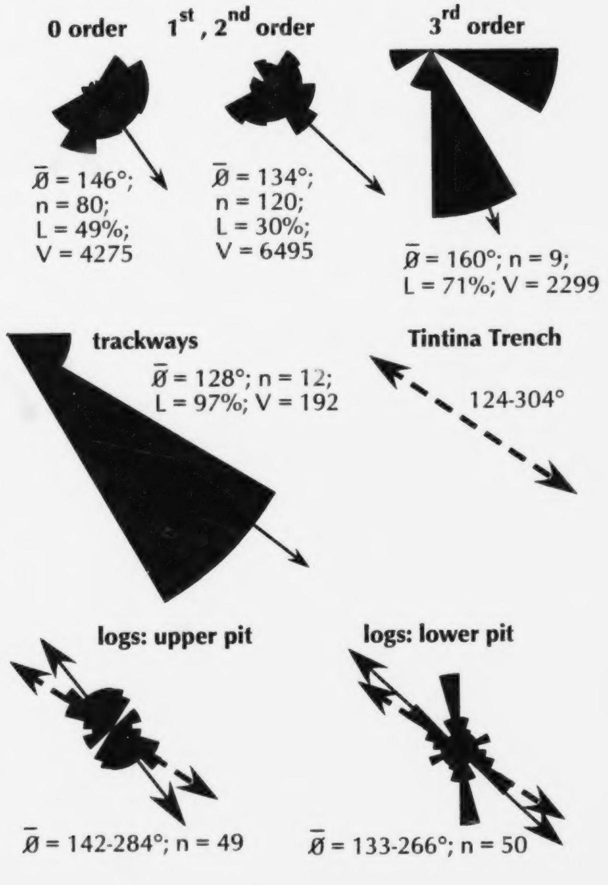


Figure 11. *Dip-corrected paleocurrent trends of 0 order (foresets), 1st and 2nd order (macroforms) and 3rd order and higher structures; dinosaur trackways, the Tintina Trench, and elongate logs from beneath the lower coal in the lower pit. $\overline{\varnothing}$ = mean paleoflow direction; n = number of readings; L = one standard deviation; V = variance.*

PALYNOLOGY

Sweet (1999) conducted a palynological investigation of ten samples from the Ross River fault-bounded block. The quality of the preservation of miospores in these samples was typically poor due to their relatively high organic maturity. Two samples, however, contained a relatively rich flora that in combination included: *Appendicisporites sp., bisaccate pollen, Cerebropollenites mesozoicus, Cicatricosisporites sp., Clavatipollenites hughesii, Cupuliferoidaepollenites minimus, Cycadopites sp., Deltoidospora sp., Microreticulatisporites uniformis, Eucommiidites minor,* fungal spores, *Gleicheniidites sp., Laevigatosporites sp., Lycopodiumsporites sp., Osmundacidites sp., Retimonocolpites sp., Senectotetradites amiantopollis, Retitricolpites prosimilis, Retitricolpites virgeus, Zilvisporis sp., Cycadopites sp.* and *Stereisporites sp.*

Sweet (1999) concluded a mid-Cretaceous age, within the range of Middle Albian to possibly Cenomanian. The presence of tricolpate angiosperm pollen (*Cupuliferoidaepollenites minimus, Retitricolpites prosimilis, Retitricolpites virgeus*) and angiosperm pollen in obligate tetrads (*Senectotetradites amiantopollis*) precludes an age older than Middle Albian. The absence of more advanced forms of angiosperm pollen (tricolporate and triporate) argues against a late Cenomanian or younger age.

STRATIGRAPHY

While strata in the Ross River fault-bounded block appear to have been deposited in rivers which flowed parallel to the modern Tintina Trench, and are petrographically similar to Eocene strata at Lapie River, there is as yet no evidence that the paleovalley was controlled by the Tintina fault zone or the St. Cyr Fault, or that either fault was active during deposition of the late Early Cretaceous strata.

Correlation of strata containing dinosaur tracks in the Ross River area with lithostratigraphic units in southern Yukon is not certain at this time. However, strata in the Ross River area are lithologically and palynologically similar to strata in the Indian River area (Lowey, 1982, 1983 a,b; Lowey and Hills, 1988; Lowey et al., 1986). The Indian River area is located south of Dawson City and south of the Tintina fault zone. Strata in this area consist of interbedded sandstone, shale, conglomerate and coal that was assigned to the Tantalus Formation by Lowey and Hills (1988). It is informally subdivided into a lower, varicoloured chert-pebble conglomerate and sandstone unit (approximately 50 m thick) and an upper, quartz-vein pebble conglomerate and sandstone unit (approximately 450 m thick). The sedimentary rocks contain a rich and varied microflora assemblage that is dominated by terrestrial palynomorphs (such as *Appendicisporites crimensia, A. erdtmanii, A. potomacensis, A. unicus, Cicatricosisporites augustus, C. hallei, C. imbricatus, C. perforatus, Deltoidospora juncta, Gleicheniidites circinidites, Lycopodiumsporites expansus, L. reticulumsporites*), but also includes dinoflagellates (i.e., *Muderongia asymmetrica, M. sp.*; Lowey, 1984). Lowey (1984) concluded that the palynomorph assemblage indicates the sedimentary rocks in the Indian River area are Early Cretaceous (Middle to Late Albian) in age and were deposited principally in a fluvial or freshwater lacustrine environment with intervals of brackish or marine deposition.

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The Stewart River placer project, west-central Yukon

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ABSTRACT

The Stewart River map area (115 O&N) is the most important historic and current placer gold producing region in the Yukon. Unfortunately, the historic placer-gold deposits are becoming depleted, and more efficient mining of existing deposits and exploration for new deposits must be encouraged. Although placer deposits in the Klondike district are well described and their origin is quite well understood, placer deposits in the remaining part of the Stewart River map area have not been so well documented. The purpose of the Stewart River placer project is to describe and document the geology of known placer deposits, to interpret the formation of the placer deposits, and to relate the geology of the placer deposits to the regional surficial and bedrock geology. The objectives of the project are to aid in the exploration and mining of placer deposits by providing a comprehensive and up-to-date placer geoscience database. The utility of the placer database is that it can be used to construct placer deposit models (general summaries of given placer settings). These models then serve as predictors for future placer exploration and mining. Fieldwork for the project began in 1998 and will be completed in 2001; results of the project will be published in a final report and a resource appraisal map for placer gold.

RÉSUMÉ

La région de Stewart River (115 O et N) est la plus importante région productrice d'or placérien au Yukon, à la fois sur le plan historique et actuel. Malheureusement, les placers historiques s'épuisent, et il faut favoriser une exploitation plus efficace des gisements existants et la prospection pour de nouveaux gisements. Bien que les placers du Klondike et leurs origines sont bien connus, ceux des autres parties de la région de Stewart River ne sont pas aussi bien documentés. L'objet du projet des placers de Stewart River est de décrire et de documenter la géologie des placers connus, d'interpréter leur mode de formation, et d'établir le lien entre leur géologie et la géologie de surface et du socle rocheux de la région. L'objectif est de faciliter la prospection et l'exploitation des placers en constituant une base de données géoscientifique complètes et à jour sur les placers. La base de données sera d'autant plus utile qu'elle servira à construire des modèles de placers (résumés généraux des contextes). Ces modèles serviront ensuite à prévoir les programmes futurs de prospection et d'exploitation des placers. Les travaux de terrain ont débuté en 1998 et se termineront en 2001; les résultats du projet seront publiés dans un rapport final et portés sur une carte d'évaluation des ressources en or placérien.

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INTRODUCTION

The Stewart River map area (115 O&N) is located in west-central Yukon between 63° and 64°N, and 138° and 141°W (Fig. 1). The map area is the most important historic and current placer-gold producing region in the Yukon. It includes the Klondike River (i.e., Bonanza, Hunker and Eldorado creeks), Indian River (i.e., Dominion, Gold Run, Sulphur, Eureka and Quartz creeks), Sixtymile River (i.e., Little Gold, Glacier, Miller, Bedrock, Matson and Fiftymile creeks), lower Stewart River (i.e., Scroggie and Barker creeks), Yukon River (i.e., Thistle, Kirkman and Frisco creeks), and White River (i.e., Moosehorn Range) drainage basin. Together, these drainage basins produced nearly 300,000 ounces of gold during 1995-97, or about 85% of the Yukon's placer-gold production (Mining Inspection Division, 1998). Unfortunately, continuous mining for nearly 100 years has almost depleted the historic placer gold producing areas, and more efficient mining of existing deposits and the exploration for new placer deposits must be encouraged.

Placer deposits in the Klondike and Indian River drainage basins have been extensively studied, including published government and consulting reports (Gleeson, 1970; Hester, 1970; Knight et al., 1994; Lowey, 1998; McConnell, 1905, 1907; Milner, 1976; Tempelman-Kluit, 1982; Tyrell, 1907, 1912) and eight university theses (Christie, 1996; Dufresne, 1987; Froese, 1997; Hoymann, 1990; Morison, 1985; Mustart, 1956; Ray, 1962; Rushton, 1991). Consequently, these deposits are well described and their origin is quite well understood. However, placer deposits in the remaining part of the Stewart River map area have not been so well documented. The available reports pertaining to placer geology for the western and southern part of the Stewart River map area include the following: the general geology of the western part of the Stewart River map area by Cockfield (1921); an outdated report on placer mining on Scroggie, Barker, Thistle and Kirkman creeks (Cairnes, 1917); a brief description of the geology of the Moosehorn Range by Morin (1977); a Masters thesis on the origin of gold in the Sixtymile area by Glasmacher (1984); a Masters thesis on the geomorphology of placers in the Sixtymile area by Hughes (1986); several government reports on the gold potential of high-level terraces in the lower Stewart River and Sixtymile River areas (Fuller, 1994, 1995); a brief report on the placer geology of Blackhills Creek (Fuller and Anderson, 1993); a report outlining the surficial geology of part of the Yukon River area south of Dawson City (Morison et al., 1998); and brief summaries of active placer mining operations by the Mining Inspection Division (1998, as well as earlier reports). In short, a comprehensive and up-to-date placer geoscience database for most of the Stewart River map area is lacking.

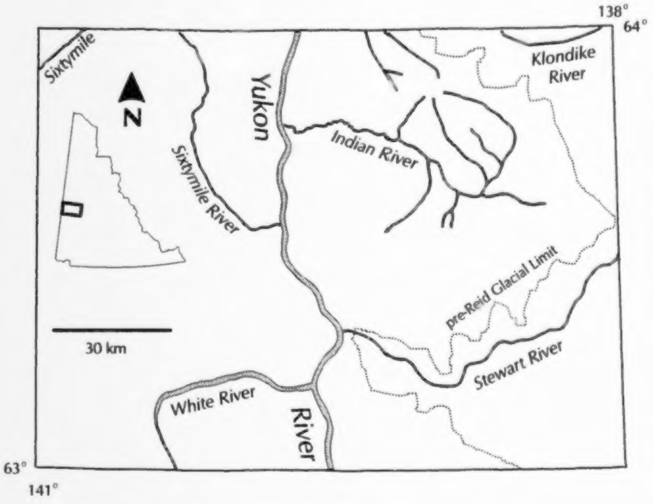

Figure 1. Location map of the Stewart River map area (115 O&N), west-central Yukon.

PURPOSE

The main purpose of this project is to describe and document the geology of known placer deposits in the Stewart River map area (i.e., deposit thickness, composition, texture, sedimentary structures, gold content and age). Other purposes of the project are to interpret the formation of the placer deposits, and to relate the geology of the placer deposits to the regional surficial and bedrock geology (particularly the NATMAP (National Mapping Program) surficial geology and bedrock geology mapping programs). The objective of the project is to aid in the mining and exploration of placer deposits in the Stewart River map area by providing a comprehensive and up-to-date placer geoscience database.

The utility of the placer database is that is can be used to construct placer deposit models. A placer deposit model is a general summary of a given placer deposit setting. Using a sluice box as an analogy, the placer deposit model is obtained from the database by 'sluicing away' local details, leaving behind the 'nuggets' or important features (Fig. 2). For example, important features of a placer deposit model for the Klondike area include gravel that is late Pliocene to early Pleistocene in age, quartz-rich, and preserved on high- to mid-level terraces (i.e., the White Channel Gravel; Lowey, 1998). These important features then act as a norm for comparison (i.e., placer deposits from other areas can be compared and contrasted), as a framework for future observations (i.e., what types of data should be recorded from placer deposits from other areas), as a basis for interpretation (i.e., the environment of deposition and the hyrodynamics of the stream flow forming the placer deposit), and most importantly, as a predictor for future placer exploration and mining (i.e., the grade and lateral and vertical continuity of the pay streak of the placer deposit can be inferred). The placer deposit model thus serves as an ore deposit model, similar to those used in mineral exploration for lode deposits (Hodgson, 1993).

METHODS

The project mainly involves visits to active and abandoned placer mines. Fieldwork consists of placer deposit mapping, which includes constructing profiles of two-dimensional exposures of placer deposits (mostly pit walls of placer mining operations). These profiles are essentially 'vertical geologic maps' and they are constructed in much the same way. They begin with a base map — a line drawing or photo-mosaic of the pit wall; foot traverses are then made across the profile, and sedimentologic and stratigraphic observations and measurements are recorded on the base map. In addition, sedimentary structures or contacts are 'walked-out', and samples are collected for grain-size, lithological, whole-rock and geochemical analyses, as well as fossil and radiometric age-dating analysis. A three-page field report form is used to record these observations (Fig. 3), and this data is eventually entered into the Placer MINFILE database.

WORK COMPLETED

Three field seasons have been completed to date. Placer settings examined include deposits in the Klondike River drainage (i.e., Bonanza, Hunker, Last Chance, Eldorado, Gold Bottom and Bear creeks), the Indian River drainage (i.e., Dominion, Gold Run, Sulphur, Eureka, Quartz, Montana and Little Blanche creeks), the Sixtymile River drainage (i.e., Little Gold, Glacier, Miller, Bedrock, Matson, TenTenmile and Fiftymile creeks), the lower Stewart River drainage (i.e., Black Hills, Henderson, Brewer, Scroggie and Barker creeks), the Yukon River drainage (i.e., Thistle, Kirkman, Excelsior and Frisco creeks), and the White River drainage (i.e., Moosehorn Range).

WORK PLANNED

One final summer of fieldwork is planned to complete this project. During July and August, 2001, fieldwork will include visits to placer mines in the Maisy May and Henderson creek drainage basins, and due to active mining, placer deposits along Thistle, Dominion and Montana creeks will be re-examined. Placer exploration sites in the North Ladue River area will also be investigated.

PROJECT HIGHLIGHT

Most of the placer gold in the Stewart River map area was deposited in a fluvial environment, and it is known that changes in the base level of a stream (i.e., the level to which a stream erodes its base; Miall, 1996) are controlled by changes in tectonics, sea level or climate. Also, changes in base level result in changes in accommodation space (i.e., the space

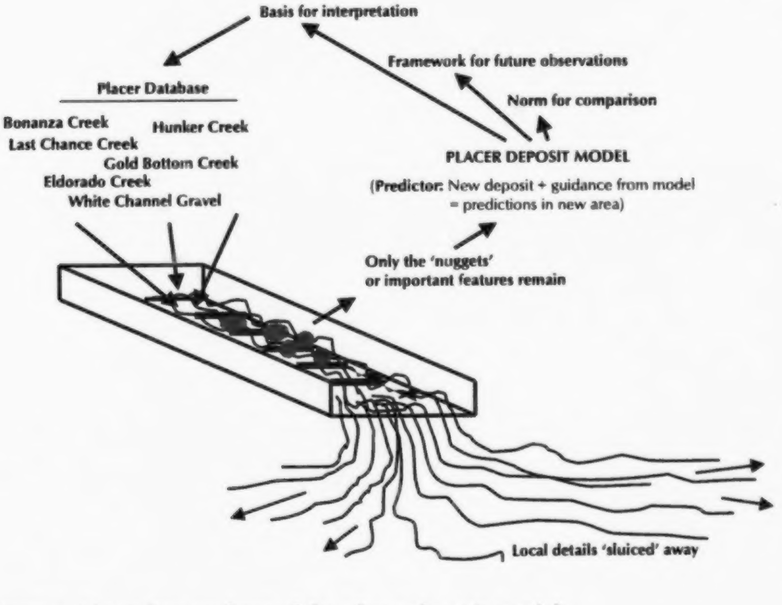
Basis for interpretation
Framework for future observations
Norm for comparison
Placer Database
Bonanza Creek
Hunker Creek
Last Chance Creek
Gold Bottom Creek
Eldorado Creek
White Channel Gravel
PLACER DEPOSIT MODEL
(Predictor: New deposit + guidance from model = predictions in new area)
Only the 'nuggets' or important features remain
Local details 'sluiced' away

Figure 2. *Sluice box analogy of the placer deposit model.*

made available for potential sediment- and placer-gold-accumulation). Very little is known about the neotectonics of the Stewart River map area, and the map area is considered too far inland to have been affected by changes in sea level. An important highlight from this project is the realization that climatic change, due to repeated cycles of glaciation related to the pre-Reid, Reid and McConnell glacial events, has had an important influence on the formation of placer gold deposits in the Stewart River map area. Climatic change, caused by orbital forcing (i.e., changes in the Earth's eccentricity, obliquity and precession), has been invoked to explain lithological cyclicity in a variety of sedimentary environments (Waterhouse, 1999; Williams et al., 1998). Placer deposits in the Stewart River map area display a cyclicity, preserved as several levels of gold-bearing gravel terraces, related to the aggradation and incision of the gravel. Vandenberghe (1993) has shown how climate-controlled variations in runoff and sediment supply, due to cycles of glacial and interglacial phases, result in cycles of stream aggradation and incision. A change from the initiation of glaciation to the maximum glacial phase

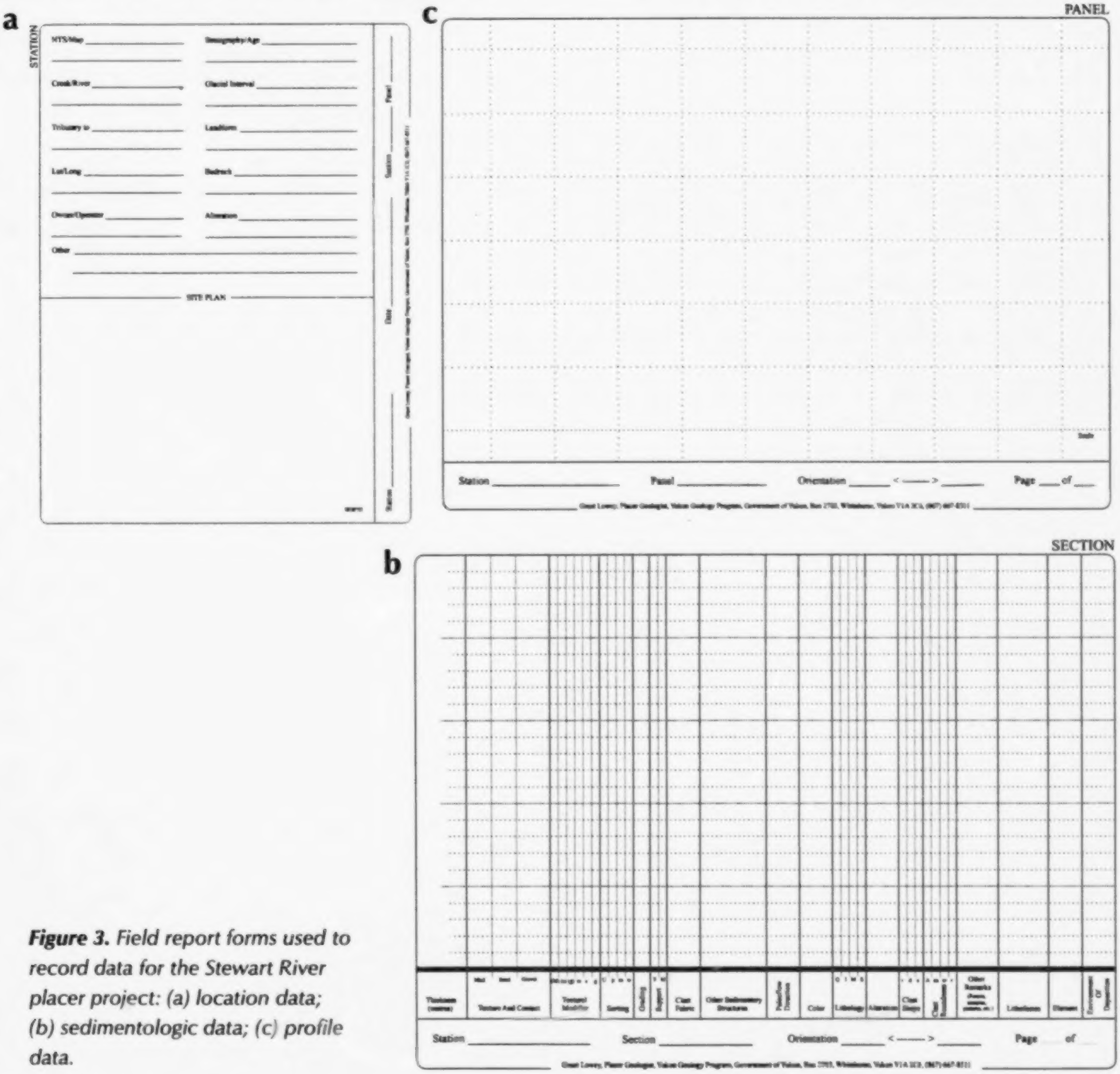
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Figure 3. Field report forms used to record data for the Stewart River placer project: (a) location data; (b) sedimentologic data; (c) profile data.

causes a relative increase in runoff and a dramatic increase in sediment supply (as vegetation disappears and slopes become unstable), resulting in aggradation. A change from a glacial to interglacial phase causes a dramatic increase in runoff and a decrease in sediment supply (as limited amounts of vegetation reappear and slopes become stabilized), resulting in incision. For example, pre-Reid glaciation (and subsequent climatic change) in the Klondike area led to a relative increase in runoff and an increase in sediment supply, corresponding to a rise in base level and an increase in accommodation space. This resulted in aggradation or deposition of the White Channel Gravel and accompanying placer gold (Figs. 4 and 5). Conversely, deglaciation (and subsequent climatic change) in the Klondike area led to an increase in runoff and decrease in sediment supply, corresponding to a lowering of base level and a decrease in accommodation space. This resulted in incision or the erosion of the White Channel Gravel and the subsequent formation of the terraces. Climatic change related to the Reid and McConnell glacial events also produced cycles of aggradation and incision, but the resulting gravel terraces are less extensive and not as well developed as terraces composed of the White Channel Gravel.

PRODUCTS

Beginning in 1998, both oral and poster presentations were made at the Yukon Geoscience Forum (Whitehorse) and the International Gold Show (Dawson). An oral and poster presentation was also given at the CANQUA-CGRG Joint Conference (Calgary, 1999), and an abstract of that talk was published in the conference program (Lowey, 1999a). Similar presentations regarding this project are planned for 2001. In addition, yearly reports have been published in Yukon Exploration and Geology (Lowey, 1999b, 2000). The final product of this project will be a report (either Open File or Bulletin format) that describes and interprets the stratigraphy and sedimentology of the placer deposit settings. The report will include chapters on the stratigraphy of the placer deposits, the sedimentology of placer gold 'trapsites', a description of the placer settings according to drainage, and a discussion on the placer potential of the Stewart River map area. The report will also include a 'resource appraisal map for placer gold' (at 1:250 000 scale) that ranks the geologic probability for occurrence of placer gold deposits in the map area.

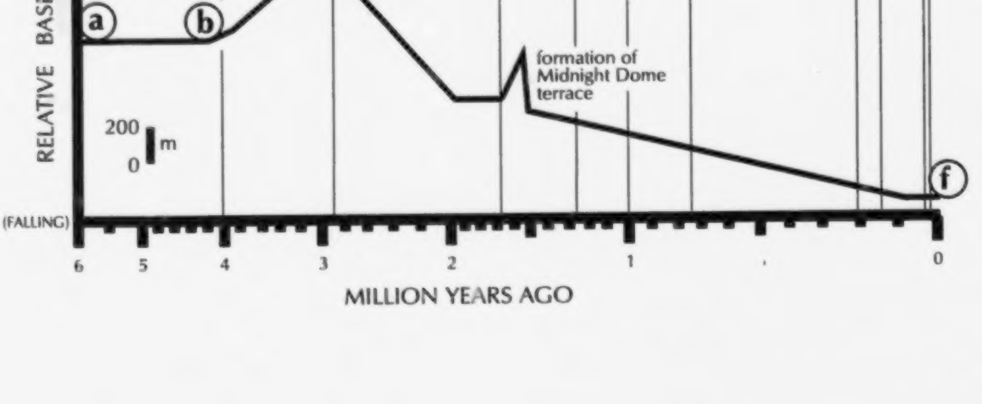

Figure 4. *Graph of base level versus time, showing the relationship between climatic change and placer formation in the Klondike area (letters refer to paleogeographic diagrams in Fig. 5).*

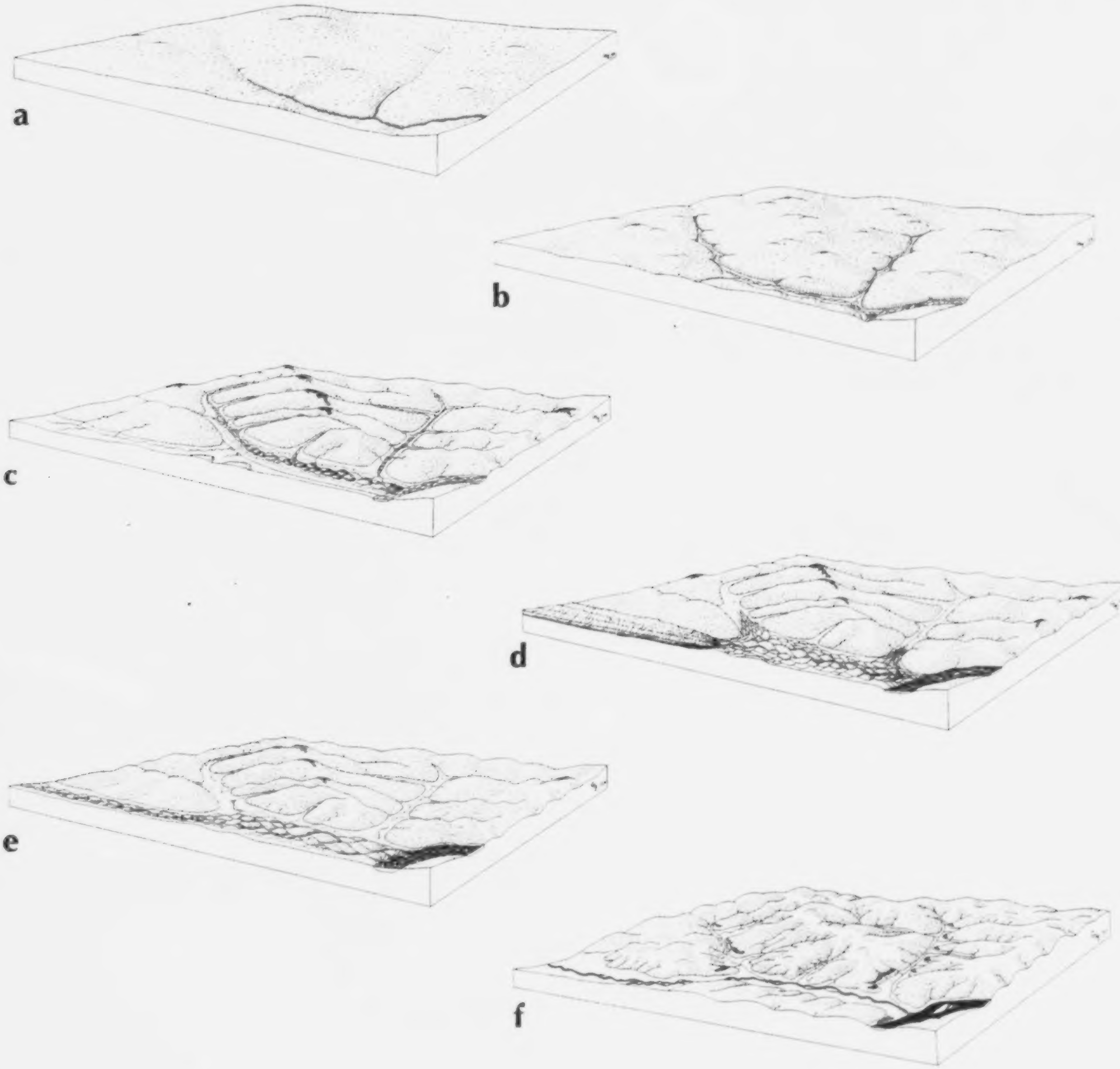

Figure 5. *Summary of the paleogeographic evolution for the Klondike area, southward view (letters refer to positions on the graph in Fig. 4): (a) ~6 million years ago (m.y.), following several million years of chemical weathering; (b) ~4 m.y., base level begins to rise due to climatic change brought about by the impending pre-Reid glaciation, and deposition of the gold-bearing White Channel Gravel begins; (c) ~3 m.y., base level continues to rise and the White Channel Gravel reaches a maximun thickness; (d) ~ 2.9 m.y., base level is still rising, the pre-Reid glaciation has reached a maximum extent, and deposition of the White Channel Gravel ends; (e) ~ 2.8 m.y., base level reaches a maximum elevation as the pre-Reid glaciation ends, resulting in the deposition of the glaciofluvial Klondike Gravel; (f) Klondike area today, showing the White Channel Gravel and Klondike Gravel terraces that formed as a result of a sudden drop in base level during pre-Reid deglaciation.*

A REQUEST

This project relies mainly on mapping existing mining pit exposures to determine the stratigraphy and sedimentology of the various placer deposit settings in the Stewart River map area. However, pit exposures provide only a two-dimensional view of the geology of the placer deposits (i.e., the height and width of gravel in the pit wall). In order to make the final report of this project as comprehensive and useful as possible to the placer exploration and mining community, it is desirable to add a 'third-dimension' to the geology (i.e., cross-sections of the placer creeks showing changes in the thickness of the gravel). These cross-sections could be constructed from drill logs. Miners are encouraged to send the author representative drill logs of mined areas, or areas being currently mined. Cross-sections of these creeks, if available, would also be useful for compilation of the final report.

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I am grateful to all of the placer miners that permitted me access to their properties. Rachel Pugh and Andrew McNeil performed admirably as summer fieldwork assistants during 1999 and 2000, respectively.

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Paleomagnetic study of the Late Cretaceous Seymour Creek stock, Yukon: Minimal geotectonic motion of the Yukon-Tanana Terrane

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ABSTRACT

Paleomagnetic results are presented for 154 specimens from 16 sites in the Late Cretaceous Seymour Creek stock, a small granodioritic intrusion emplaced into Paleozoic gneisses and schists of the Yukon-Tanana Terrane (YTT), west-central Yukon. Stepwise demagnetization of the specimens revealed steep characteristic remanent magnetization directions in 2 normal- and 14 reversed-polarity sites with a mean direction of declination D=65.0°, inclination I=-83.6° (α_{95}=4.3°, k=73.8). Geological relations suggest that the stock has not been tilted since its emplacement at 68.5 ± 0.2 Ma. The paleopole for the Seymour Creek stock at 55.2°N, 202.5°E (dp=8.3°, dm=8.5°), plots south of the North American apparent polar wander path. This suggests that the YTT has experienced a net 79° ± 36° counter-clockwise rotation, and a nonsignificant 2.4° ± 7.5° anti-poleward translation relative to North America since 68.5 Ma. This result does not agree with the previously reported large poleward translation and minimal rotation estimated for the YTT from paleomagnetism of the coeval Carmacks Group volcanic rocks.

RÉSUMÉ

Les résultats d'une étude paléomagnétique sont présentés pour 154 échantillons prélevés à 16 sites au sein du massif intrusif de Seymour Creek ; une petite intrusion granodioritique d'âge Crétacé supérieur située dans les gneiss et les schistes paléozoïques du Terrane Yukon-Tanana (YTT), dans le centre-ouest du Yukon. Une démagnétisation par étape des échantillons a révélé des directions d'aimantation rémanente abruptes caractéristiques dans 2 sites à polarité normale et 14 sites à polarité inversée – direction moyenne de la déclinaison : D = 65,0E, inclinaison I = -83,6E (α95 = 4,3E, k = 73,8). Les relations géologiques semblent indiquer que le massif intrusif n'a pas été basculé depuis son intrusion il y a 68,5 ± 0,2 Ma. Le paléopole du massif intrusif de Seymour Creek, à 55,2EN, 202,5EE (dp = 8,3E, dm = 8,5E) se situe au Sud de la trajectoire du déplacement polaire apparent pour l'Amérique du Nord. Cela semble indiquer que l'YTT a subi, depuis 68,5 Ma, une rotation nette de 79E ± 36E dans le sens anti-horaire et une translation non significative de 2,4° ± 7,5° en direction opposée du pôle par rapport à l'Amérique du Nord. Ces résultats ne concordent pas avec la translation dans le sens du pôle signalée auparavant et la rotation minimale estimée pour l'YTT par l'étude paléomagnétique des roches volcaniques contemporaines du groupe de Carmacks.

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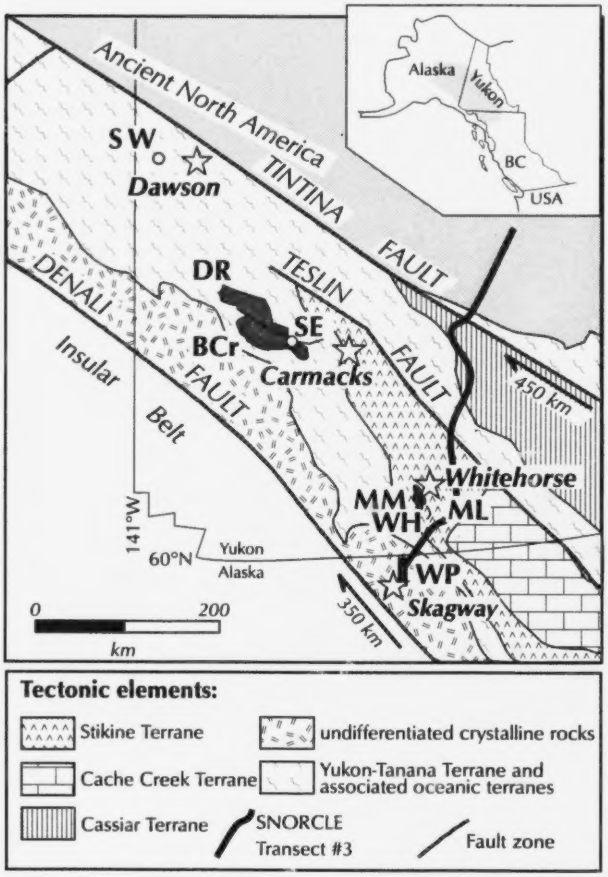
INTRODUCTION

The enigmatic Yukon-Tanana Terrane (YTT) is a mostly Paleozoic assemblage of continentally derived rocks with uncertain past relations to the far-travelled allochthonous terranes of the Cordillera, and to the North American craton (Mortensen, 1992; Monger, 1997). Its large size, cratonic provenance, and 'inboard' Cordilleran position (Fig. 1) make the YTT a key tectonic element in the evolution of the northwestern Cordillera.

Paleomagnetic studies of well dated Mesozoic and Cenozoic intrusions in the YTT are being performed under the aegis of the lithoprobe-SNORCLE (Slave-Northern Cordillera Lithospheric Evolution) transect to provide estimates of past geotectonic motions for the YTT relative to North America and other Cordilleran terranes.


Ancient North America
TINTINA
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Carmacks
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Whitehorse
MM
ML
WH
WP
Skagway
350 km
141°W
60°N
Yukon
Alaska
0
200
km
Alaska
Yukon
BC
USA
Tectonic elements:
Stikine Terrane
undifferentiated crystalline rocks
Cache Creek Terrane
Yukon-Tanana Terrane and associated oceanic terranes
Cassiar Terrane
SNORCLE Transect #3
Fault zone

Figure 1. *Yukon-Tanana Terrane (YTT) context and selected intrusive rocks from which paleomagnetic results have been reported: BCr - Big Creek batholith; DR - Dawson Range batholith; ML - Mount Lorne stock; MM - Mount McIntyre pluton; SE - Seymour Creek stock; SW - Swede Dome stock; WH - Whitehorse batholith; WP - White Pass dykes.*

At question is the role of the YTT in the Mesozoic-to-Eocene accretion and poleward translation of the Intermontane Belt exotic terranes along the western margin of North America (Irving and Wynne, 1990; Irving et al., 1996). Did the YTT participate, at least in part, with motions of the Intermontane Belt terranes relative to North America (Irving et al., 1996; Johnston et al., 1996), or did it act as an *in situ* 'bumper' to halt the motion of the accreted terranes (McClelland et al., 1992; Mihalynuk et al., 1994; Symons et al., 2000b)?

Previously reported paleomagnetic results from the 70.2 ± 3.3 Ma Upper Cretaceous Carmacks Group volcanic rocks (Marquis and Globerman, 1988; Johnston et al., 1996; Wynne et al., 1998) have hitherto provided the only tectonic motion estimates for the YTT that bear on northwest Cordilleran evolution during the Cretaceous. Paleomagnetism of the Carmacks Group implies that the underlying YTT and northern Intermontane Belt terranes resided 1900 km ± 700 km south of their present North American position during the Late Cretaceous (Wynne et al., 1998). Paleomagnetic results reported here from the coeval 68.5 ± 0.2 Ma Seymour Creek stock differ markedly, implying that the YTT has had only a minimal net displacement with respect to North America since the Late Cretaceous.

GEOLOGY

The Seymour Creek stock is a recessive weathering, ovoid, 4 km^2 intrusion that is exposed ~50 km northwest of Carmacks in west-central Yukon (Figs. 1, 2). The stock, with associated dykes, intrudes Paleozoic gneissic and metasedimentary rocks of the YTT as well as the undeformed Early Jurassic Big Creek and mid-Cretaceous Dawson Range batholiths (Tempelman-Kluit, 1984). Intrusive contacts are poorly exposed, however, and the stock is adjacent to the northwest-trending Big Creek Fault, which cuts flat-lying Upper Cretaceous Carmacks Group volcanic rocks ~30 km to the northwest of the map area. Aeromagnetic data indicates that the western part of the stock may have been cut by the fault. Displacement is likely minor, in agreement with the minor offsets of Carmacks flows across the fault in the northwest.

The Seymour Creek stock ranges from massive biotite-hornblende granodiorite to quartz monzonite. The southeastern portion is cut by a late irregular andesitic dyke, sampled as site 13 (Fig. 2). The dyke is ~1 m in width and dips steeply to the east. Additionally, swarms of northwest-trending dykes that are lithologically similar to the Seymour Creek stock intrude the Big Creek batholith up to several kilometres south of the stock itself, across the possible continuation of the Big Creek Fault (Fig. 2). One of these dykes was sampled as site 5.

Samples from the stock have a characteristic pink-to-grey, variably milky appearance, usually with a medium-grained (~1-2 mm) igneous texture. In thin section, most samples have 25-40% euhedral alkali feldspar, 15-50% variably sericitized plagioclase, and 20-30% subhedral to interstitial quartz. Green pleochroic biotite is the dominant mafic mineral, ranging up to 5%, and hornblende is locally present as single, large, partly chloritized phenocrysts. Titanite, apatite, zircon and magnetite are accessory minerals. Alteration is limited to variable sericitization of plagioclase and replacement of hornblende with chlorite and opaque minerals. Specimens from sites 5, 9, 11 and 12 have experienced greater alteration of plagioclase.

Geological evidence suggests that the stock has not undergone significant post-emplacement tilting because the coeval Carmacks Group volcanic rocks are near-horizontal on both sides of the Big Creek Fault in the region. Additionally, geobarometry performed on seven dispersed locations in the adjacent Early Jurassic Big Creek batholith yield a narrow range of pressure estimates averaging 441 ± 41 MPa (15.9 ± 1.5 km depth). Similar depth estimates for different locations in the batholith indicate that it has not likely undergone any post-emplacement tilting (Symons et al., 2000b).

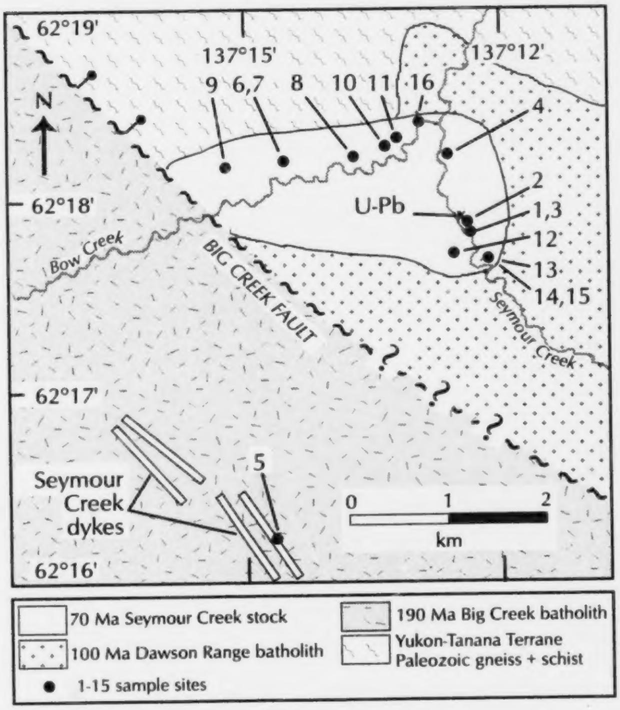

Figure 2. *Sampling sites and geology of the Seymour Creek stock. 'U-Pb' marks the sampling site for the 68.5 ± 0.2 Ma U-Pb zircon date by J.K. Mortensen.*

U-Pb age dating on zircon and titanite has yielded a crystallization age of 68.5 ± 0.2 Ma for the Seymour Creek stock (J.K. Mortensen, pers. comm., 1999), which is coeval with the widespread Carmacks andesites, basalts and tuffs, dated at 70.2 ± 3.3 Ma (average of five K-Ar and six Ar-Ar dates; Smuk et al., 1997). The stock may be comagmatic with the Carmacks Group volcanic rocks, perhaps being the core of a local volcanic centre for the extrusives (*cf.*, Johnston et al., 1996).

GEOTHERMOBAROMETRY

Crystallization pressures and temperatures for the stock were estimated using the Al-in-hornblende geobarometer (Schmidt, 1992), corrected for temperature with the plagioclase-amphibole geothermometer (Blundy and Holland, 1990; Anderson and Smith, 1995). Procedures and standards used here are as reported in Harris et al. (1997, 1999).

A polished thin section from site 7 contained the requisite mineral assemblage of hornblende, plagioclase, quartz, alkali feldspar, biotite, titanite, apatite, and magnetite-ilmenite for Al-in-hornblende geobarometry (Hammarstrom and Zen, 1986). Other sites either lacked hornblende in thin section, had plagioclase that was too sericitized, or did not provide the requisite equilibrium assemblage. Electron microprobe analyses over four traverses of a plagioclase-amphibole pair were performed using the JEOL JXA-8600 Superprobe at the University of Western Ontario.

A total of 4 analyses of plagioclase were performed, keeping away from a ~10 μm albitic rim. Using a plagioclase structural formula with 32 oxygens, these analyses provide an average Ab # of 0.78. The 4 analyses of hornblende yield an average Al^{TOT} of 1.246 using a structural formula normalized to 13 cations. Emplacement temperature and pressure are calculated to be 719°C and 245 MPa, which imply an estimated emplacement depth of 8.8 ± 2.0 km. This single-pair depth estimate is considered preliminary, pending further investigation of more plagioclase-amphibole pairs at site 7 and other sites of the Seymour Creek stock.

PALEOMAGNETISM

A total of 154 specimens were collected from 16 sites in the Seymour Creek stock. Fifteen sites were sampled along a placer mining access road northwest of Carmacks (Fig. 2), whereas site 5 was sampled by helicopter some 3 km south of the road. Most sites are represented by six 2.54-cm-diameter cores, oriented *in situ* by magnetic and/or solar compass. Standard specimens of 2.20-cm-length were sliced from each core and stored in a magnetically shielded room at the University of Windsor Paleomagnetic Laboratory that has an ambient field of 0.2% of the earth's magnetic field intensity, to allow the viscous remanent magnetization (VRM) to decay before measurement.

Specimens underwent thermal or alternating-field stepwise demagnetization in the shielded room to isolate their remanence. Measurements were performed using an automated Canadian Thin Films CTF DRM-420 cryogenic magnetometer, while demagnetization was done using a Sapphire Instruments SI-4 alternating field (AF) demagnetizer or a Magnetic Measurements MMTD-80 thermal demagnetizer.

Measurement of the specimens' natural remanence magnetizations (NRM) showed a median NRM intensity of 5.5×10^{-2} A/m for the Seymour Creek specimens (1st quartile 3.6×10^{-2} A/m; 3rd quartile 8.5×10^{-2} A/m). Specimen bulk susceptibilities were measured on a Sapphire Instruments SI-2B magnetic susceptibility meter. The Seymour Creek stock specimens had a median magnetic susceptibility of 7.3×10^3 SI units (1st quartile 5.3×10^3 SI; 3rd quartile 8.9×10^3 SI). Both the NRM

Table 1. *Summary of site mean remanence data for Seymour Creek stock.*

Site	**ChRM Demagnetization**		**n/N (A,T)**	***In situ* ChRM Direction**			
	AF (mT)	*TH (°C)*		*Dec (°)*	*Inc (°)*	*α_{95} (°)*	*k*
01	30-130	500-565	8/9 (6,2)	324.5	-88.2	6.4	75.1
02	50-130	500-580	6/7 (5,1)	78.0	-84.1	8.8	59.6
03	30-130	500-580	9/10 (7,2)	297.2	-88.7	7.3	50.7
04	50-130	500-580	13/14 (12,1)	222.8	-85.8	4.2	97.1
05[a]	60-120	500-580	5/7 (4,1)	276.9	73.4	9.3	69.1
06	50-130	500-580	7/11 (7,-)	269.5	-86.0	8.0	57.6
07	50-130	500-580	9/10 (8,1)	81.8	-87.8	6.0	75.4
08	70-130	500-580	7/9 (7,-)	9.8	-72.2	5.1	140.0
09a	30-75	500-580	6/8 (5,1)	287.2	74.9	6.5	108.9
10	70-130	525-580	7/8 (6,1)	37.6	-82.9	7.7	62.9
11[a]	70-130	500-580	9/9 (7,2)	44.9	-76.7	5.7	83.8
12	50-130	500-580	8/8 (6,2)	74.6	-72.1	11.5	24.0
13[b]	50-130	525-580	12/12 (10,2)	139.6	-79.7	2.0	481.0
14	50-130	500-580	11/11 (9,2)	73.6	-75.8	5.0	83.5
15	50-130	500-580	4/10 (3,1)	72.0	-83.4	11.8	62.0
16	50-130	450-580	11/11 (9,2)	9.2	-75.9	6.3	53.5
		Reversed 14	N=14 sites	51.1	-84.3	4.4	82.2
		All 16 sites	N=16 sites	65.0	-83.6	4.3	73.8

ChRM Demagnetization: Range of demagnetization steps in alternating field (AF - in milliTesla) and thermal (TH – in degrees Celcius) over which the ChRM was isolated. n/N: Number of specimens useable for site mean ChRM calculation/total number of specimens in site; (A,T) - number of AF- and TH-demagnetized specimens contributing to site mean ChRM. Site mean ChRM directions given by: Dec – declination; Inc – inclination; α_{95} – radius of 95% cone of confidence, and *k* – precision parameter. Notes: [a]- remagnetization circles (Halls, 1976; Bailey and Halls, 1984) used in part to obtain site mean ChRM direction; [b]- late andesitic dyke.

intensities and bulk susceptibility values found here are normal for coarse-grained felsic intrusive rocks. However, specimens from sites 5 and 9 showed anomalously low (1.4×10^3 SI) and high (17.1×10^3 SI) median susceptibility values, respectively, while the site 13 andesitic dyke specimens gave somewhat elevated values (12.2×10^3 SI), reflecting their greater magnetic mineral content, as expected in more mafic rocks.

After the NRM measurements, two pilot specimens per site were AF demagnetized in 12 steps up to 130 mT and two others were thermally demagnetized in 13-16 steps up to 580°C to 680°C. AF demagnetization more clearly defined consistent characteristic remanent magnetization (ChRM) directions, so all remaining specimens were AF demagnetized in six steps from 30 mT to 130 mT. A ChRM vector was obtained over three or more consecutive steps for each specimen by the least-squares method of Kirschvink (1980), with a maximum angular deviation of <15° for the fitted line. Sites 5, 9 and 11 each failed to provide a sufficient number of specimens with stable ChRM endpoints to calculate a site mean, so their ChRM information was also recovered from the non-stable endpoint specimens using remagnetization circles (Halls, 1976; Bailey and Halls, 1984). Site and collection mean ChRM directions (Table 1) were derived using Fisher (1953) statistics.

Thermal step demagnetization curves do not indicate goethite and pyrrhotite to be significant remanence carriers. Instead, specimens from the Seymour Creek stock display distributed unblocking temperature curves with sharp drops in intensity between 525°C and 565°C, diagnostic of magnetite as the remanence carrier (Fig. 3). For 11 specimens, saturation isothermal remanent magnetization (SIRM) acquisition and decay curves were obtained using a Sapphire Instruments SI-6 pulse magnetizer by magnetizing them in 14 direct field steps up to 900 mT and then demagnetizing them in 7 AF steps up to 130 mT. SIRM acquisition and decay curves confirm pseudosingle to multidomain magnetite to be the dominant remanence carrier (Fig. 4).

In most specimens, a viscous remanent magnetization (VRM) is removed by AF demagnetization up to ~30 mT (Fig. 5a), but it persists on thermal demagnetization beyond 260°C to as high as 450°C (Fig. 5b). The VRM is mostly directed steeply down to the north-northeast and often contributes more than 50% to the NRM intensity. It is likely a present-day earth's magnetic field overprint in the low-coercivity magnetic domains.

The ChRM for most specimens is isolated between ~50 mT and ~130 mT, or between ~500°C and ~580°C (Fig. 5) as a steep remanence vector in 2 normal- and 14 reversed-polarity sites. Sites 9 and 5 carry normal-polarity ChRM directions (Fig. 5c). Their site means have been inverted through the origin to their antipodal directions for inclusion with the reversed ChRM mean directions found in other sites (Fig. 6). Site 13, the andesitic dyke, retains a well defined steeply upwards ChRM direction with tightly clustered specimen directions (Table 1), consistent with their remanence having been acquired during rapid cooling when the dyke intruded the cooled

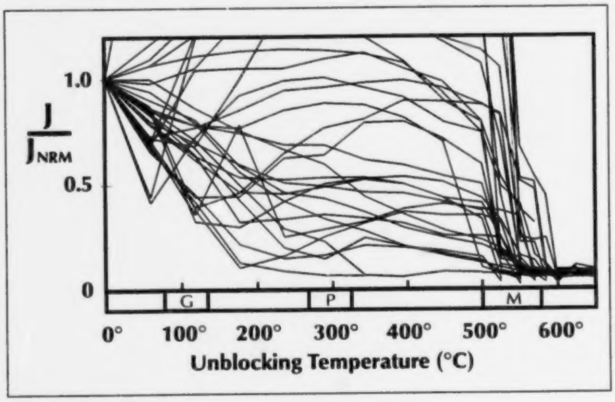

Figure 3. *Thermal demagnetization curves of 32 thermal pilots for Seymour Creek stock. G, P and M refer to the diagnostic unblocking temperature ranges of goethite, pyrrhotite and magnetite, respectively.*

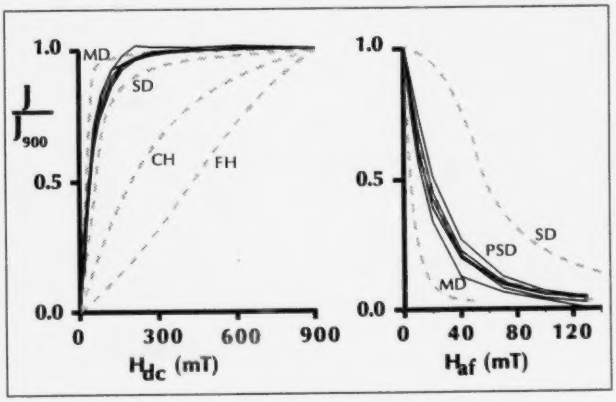

Figure 4. *SIRM acquisition (left) and decay (right) curves. MD - multidomain magnetite; SD - single domain magnetite; CH - coarse hematite; FH - fine hematite; PSD - pseudosingle domain magnetite.*

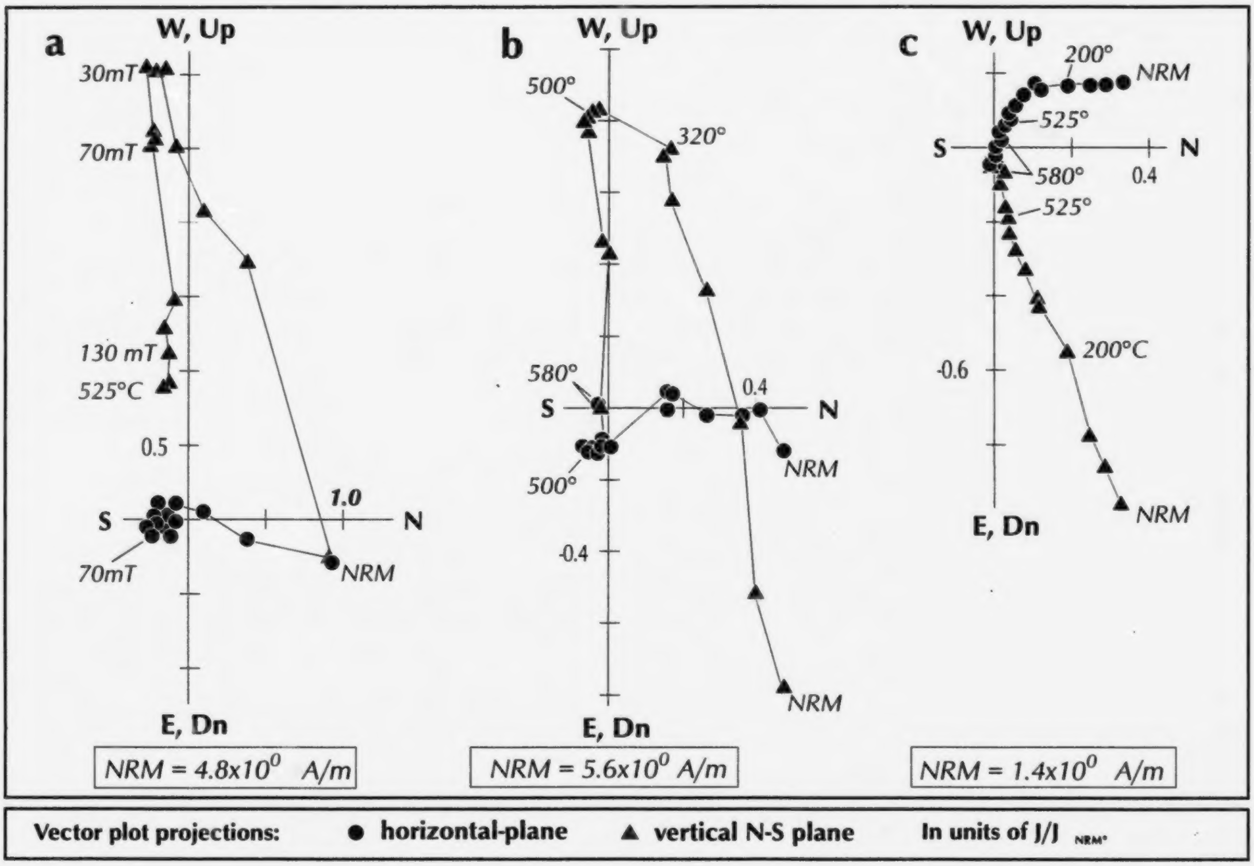

Figure 5. *Stepwise demagnetization vector plots for reversed ChRM in specimens from: (a) site 6, (b) site 4, and (c) for a normal ChRM at site 9.*

stock. The andesitic dyke may be a feeder for the overlying Carmacks Group volcanic rocks.

The mean ChRM direction calculated for all 16 sites has a declination of $D=65.0°$ and inclination $I=-83.6°$, with a radius for the cone of 95% confidence of $\alpha_{95}=4.3°$ and a precision (directional dispersion) parameter of $k=73.8$ (Fig. 6; Table 1).

A primary origin for the Seymour Creek stock's ChRM is implied by its dual-polarity remanence and by the significantly different direction of the older ChRM found in the adjacent Big Creek batholith, which shows no sign of an overprint remanence (Symons et al., 2000a,b). Assuming a geothermal gradient of 30°C/km, the maximum burial temperature of the Seymour Creek stock at ~9 km depth would be ~270°C. The Seymour Creek ChRM is isolated between demagnetization temperatures of 500°C to 580°C, which correspond to acquisition temperatures of >350°C over a geologically reasonable time (Pullaiah et al., 1975). The Seymour Creek ChRM was evidently acquired as a primary thermoremanent magnetization upon the emplacement of the stock at 68.5 Ma, and has not been significantly disturbed since.

DISCUSSION

The unit mean ChRM direction for the Late Cretaceous Seymour Creek stock yields a paleopole at 55.2°N latitude, 202.5°E longitude, with a 95% confidence oval (Fisher, 1953) defined by poleward and perpendicular radii to the stock-paleopole great circle of $dp=8.3°$ and $dm=8.5°$, respectively. When compared with the 70 Ma North American reference pole of Besse and Courtillot (1991) at 72.3°N, 192.7°E ($A_{95}=4.1°$), the estimated net tectonic motion of the YTT at Seymour Creek is a

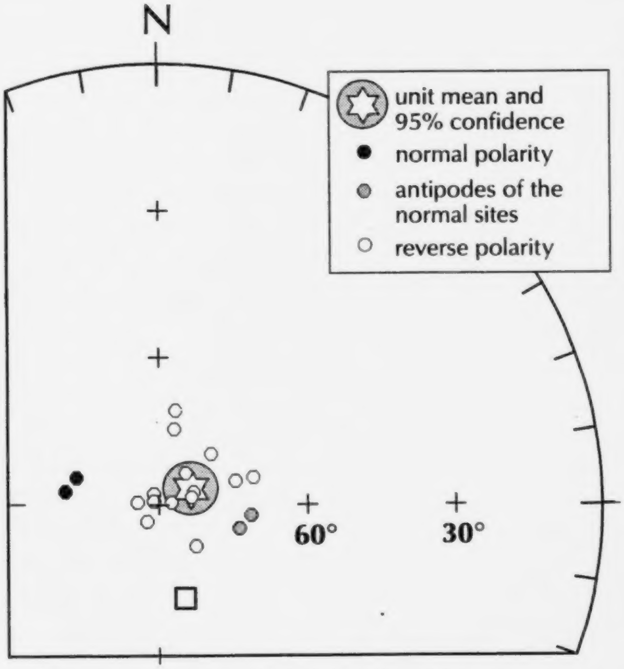

Figure 6. *Equal area stereoplot of site and unit mean ChRM directions for the Seymour Creek stock (16 sites). The open square marks the mean direction reported for the Carmacks Group volcanic rocks by Wynne et al. (1998).*

nonsignificant translation of 2.4° ± 7.5° (267 ± 831 km) away from the pole, or southwards relative to the North American craton, with a significant counter-clockwise (CCW) rotation of 79° ± 36°.

The nearby Early Jurassic Big Creek batholith provided a similar near-sided (9.3° ± 6.1°) and counter-clockwise-rotated (32° ± 11°) paleopole (Symons et al., 2000b). Both the Seymour Creek and Big Creek paleopoles are plotted in Figure 7, along with the 70 Ma Carmacks paleopole of Wynne et al. (1998), all in reference to the North American apparent polar wander path of Besse and Courtillot (1991). Unlike the far-sided and slightly clockwise-rotated Carmacks paleopole (Wynne et al., 1998) that implies 21.5° ± 7.1° of poleward translation relative to the 70 Ma reference pole of Besse and Courtillot (1991), the poles for the Seymour Creek stock and Big Creek batholith indicate CCW rotation and little or no translation relative to their coeval North American cratonic reference poles. Also shown in Figure 7 are preliminary YTT results from the 100 Ma Dawson Range batholith and the 70 Ma Swede Dome stock (McCausland et al., 2000a, b), which similarly indicate minimal translation of the YTT relative to North America.

The 75-70 Ma paleopoles derived for the Seymour Creek and Swede Dome stocks in the YTT and the Mt. Lorne stock in northern Stikine Terrane (Harris et al., 1999) are of particular interest. The three paleopoles show different net rotations and translations relative to North America since late in the Cretaceous: Seymour Creek has been rotated CCW, whereas Swede Dome has not been rotated, but both show

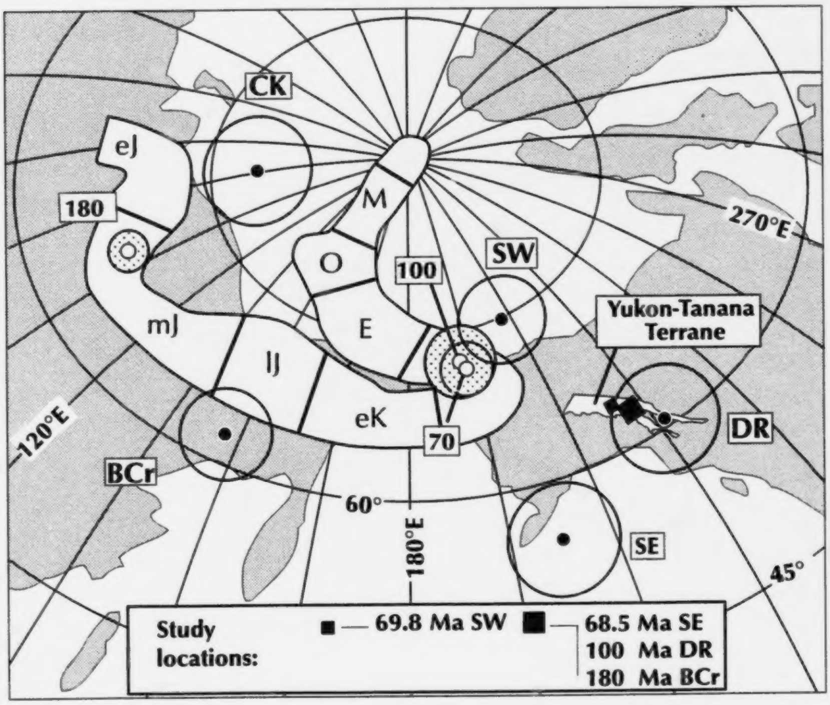

Figure 7. *YTT paleopoles with 1-sigma confidence cones relative to the North American apparent polar wander path, and its North American reference poles at 180, 100 and 70 Ma (Besse and Courtillot, 1991). Abbreviations are as follows: BCr - Big Creek batholith; CK-Carmacks Group volcanics; DR - Dawson Range batholith; SE - Seymour Creek stock; SW - Swede Dome stock. The apparent polar wander path carries epochal time divisions.*

minimal transport relative to North America. Mt. Lorne has been rotated 57° ± 11° clockwise and transported poleward by 10.5° ± 3.5° (Harris et al., 1999). One straightforward interpretation of these net motions is that the Stikine Terrane (Intermontane) had not quite collided with the YTT at 70 Ma, and that the subsequent collision may have involved some clockwise rotation of the Stikine Terrane, counter-clockwise rotation of the YTT west of Carmacks, and only minimal tectonic disruption of the central YTT to the north (Fig. 1). This, however, is in contrast to geological data that shows Carmacks Group volcanic rocks overlying both YTT and Stikine Terrane.

Figure 8 provides a comparison of Mesozoic and Cenozoic net translations relative to North America for units from the YTT and the Intermontane Belt terranes. The motion histories of these terranes are clearly convergent towards their present North American locations during the interval 110 Ma to 50 Ma. Thus paleomagnetic evidence does not place the Intermontane Belt terranes near the YTT until Eocene time. This model is in accord with accretionary models which postulate a 'bumper' role for the YTT, against which the advancing Intermontane Belt terranes impacted and overrode (McClelland et al., 1992; Mihalynuk et al., 1994), perhaps on large-scale sole faults that would have accommodated the significant differential rotations (Symons et al., 2000a, b). Note, however, that an Eocene final accretion between the Intermontane Belt terranes and the YTT is younger than the Jurassic to mid-Cretaceous timing employed in the collisional models of McClelland et al. (1992) and Mihalynuk et al. (1994).

Paleomagnetic results from the 70 Ma Carmacks Group volcanic rocks (Wynne et al., 1998) are discordant from results obtained from other Cretaceous Intermontane units (summarized in Harris et al., 1999), and strikingly different from other YTT units (Figs. 7, 8). This is puzzling since the Carmacks Group volcanic rocks extensively overlie both YTT and northern Intermontane units

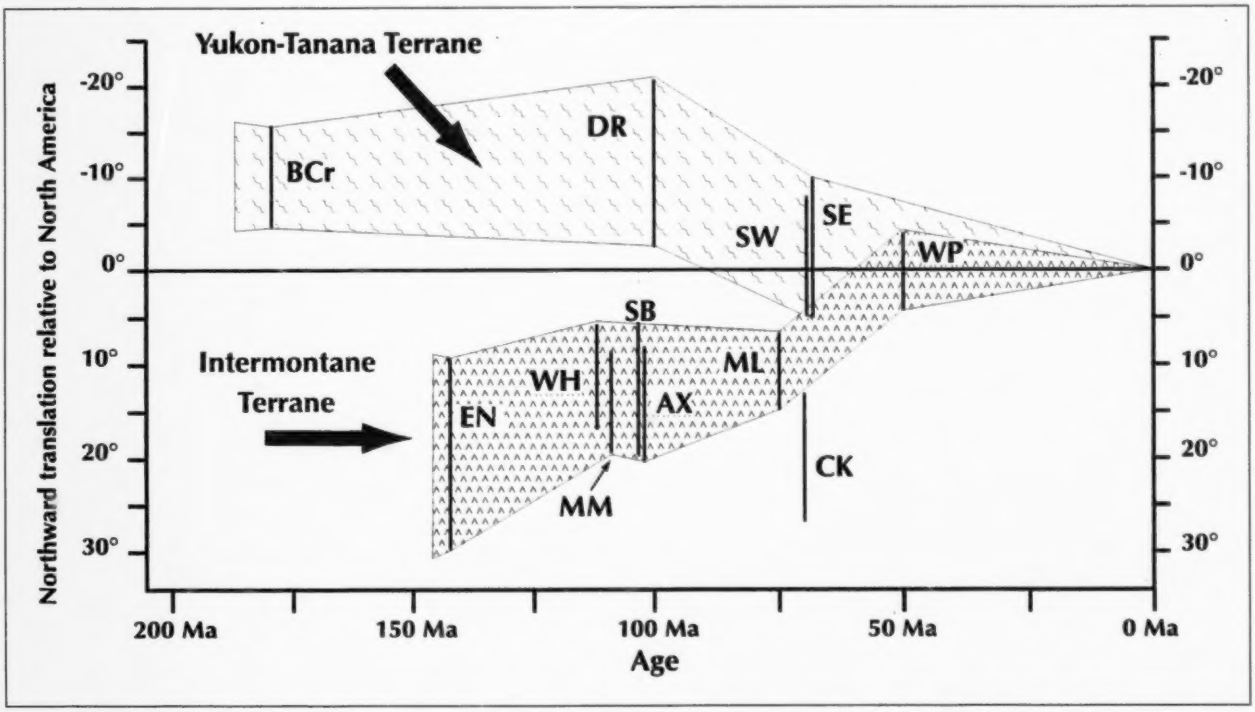

Figure 8. Intermontane Belt and YTT unit translations relative to North America. Error bars on translation estimates are the calculated uncertainty derived from the unit and reference poles' 95% confidence cones. Abbreviations are as follows: AX - Axelgold intrusions; BCr - Big Creek batholith; CK - Carmacks Group volcanics; DR - Dawson Range batholith; EN - Endako intrusions; ML - Mount Lorne stock; MM - Mount McIntyre pluton; SE - Seymour Creek stock; SP - Spences Bridge volcanics; SW - Swede Dome stock; WH - Whitehorse Batholith; WP - White Pass dykes (adapted from Harris et al., 1999).

(Johnston et al., 1996) and are likely fed by Late Cretaceous intrusions such as the Seymour Creek stock.

Further investigation of this problem is underway, through reassessment of geological relations and broadening the YTT paleomagnetic database, to refine estimates of YTT motion history, and to test its coherency throughout Mesozoic time.

ACKNOWLEDGEMENTS

The authors acknowledge the assistance of Mark Smethurst during field collection and Yves Thibault for microprobe guidance. Jaros Kulhanek and Rachel Comber assisted with paleomagnetic and rock magnetic data acquisition. Mike Harris provided useful comments on Intermontane-YTT motions. This work would not be possible without the participation and support of the Yukon Geology Program. We gratefully acknowledge the financial support of the lithoprobe-SNORCLE project, and (to PJAM) of an Ontario Government Scholarship for Science and Technology. This is lithoprobe contribution No. 1204.

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Yukon-Tanana Terrane in southwestern Frances Lake area (105H/3, 4 and 5), southeastern Yukon

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Murphy, D.C., 2001. Yukon-Tanana Terrane in southwestern Frances Lake area (105H/3, 4 and 5), southeastern Yukon. *In:* Yukon Exploration and Geology 2000, D.S. Emond and L.H. Weston (eds.), Exploration and Geological Services Division, Yukon, Indian and Northern Affairs Canada, p. 217-233.

ABSTRACT

Yukon-Tanana Terrane (YTT) in Frances Lake area consists of three domains, the Money/Jules Creek thrust sheet, the footwall of the Jules Creek thrust, and a northeastern domain defined primarily by Permian (?) conglomerate. The Money/Jules Creek thrust sheet comprises chert, dark argillite and limestone, Mississippian meta-volcanic and meta-plutonic rocks, and Pennsylvanian carbonate. A dark argillite, chert, and coarse clastic unit of probable Pennsylvanian age unconformably overlies both the hanging wall and footwall of the Money Creek thrust. The footwall of the Jules Creek thrust comprises a lower unit of dark argillite, chert, chert-pebble conglomerate, and rare sandstone, limestone and variegated chert, and unconformably overlying conglomerate and basalt. The Pennsylvanian-Permian Campbell Range basalt overlies, probably unconformably, rock units of both domains. The northeastern domain comprises mainly Permian (?) polymictic conglomerate and sandstone. Conglomerate clasts come from YTT, implying an unconformable relationship.

The back-arc rocks of YTT that host the Finlayson Lake volcanogenic massive sulphide (VMS) deposits are truncated by the Money Creek thrust; however, VMS-style prospects occur in coeval volcanic arc rocks in the Money Creek thrust sheet, attesting to the potential for new deposits in these rocks.

RÉSUMÉ

Le Terrane de Yukon-Tanana (TYT) dans la région de Frances Lake comprend trois domaines : la nappe de Money/Jules Creek; le mur du chevauchement de Jules Creek; et un domaine nord-est défini principalement par un conglomérat d'âge Permien (?). La nappe de Money/Jules Creek est constituée de chert, d'argilite noire et de calcaire, de roches métavolcaniques et métaplutoniques d'âge Mississippien, et de carbonate du Pennsylvanien. Une unité d'argilite noire, de chert et de roches clastiques grossières, probablement du Pennsylvanien, repose en discordance à la fois sur le toit et le mur du chevauchement de Money Creek. Le mur du chevauchement de Jules Creek comprend une unité inférieure composée d'argilite noire, de chert, d'un conglomérat à galets de chert et d'un peu de grès, de calcaire et de chert bigarré, surmonté en discordance d'un conglomérat et de basalte. Le basalte de Campbell Range d'âge Pennsylvanien-Permien repose, probablement en discordance, sur les unités lithostratigraphiques des deux domaines. Le domaine nord-est se compose principalement de grès et d'un conglomérat polymictique d'âge Permien (?). Les constituents du conglomérat proviennent du TYT, indiquant une relation de discordance.

Les roches d'arrière-arc du TYT qui renferment les gisements de sulfure massif volcanogénique (SMV) de Finlayson Lake sont recoupées par le chevauchement de Money Creek; toutefois, des zones d'intérêt pour des gisements de type SMV se retrouvent dans les roches d'arc volcanique contemporaines dans la nappe de Money Creek, attestant de la possibilité d'y découvrir de nouveaux gisements.

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INTRODUCTION

Geological mapping in Yukon-Tanana Terrane south of Finlayson Lake by Yukon Geology Program (Fig. 1) has had two goals since its inception in 1996: 1) to understand the geological setting of the volcanogenic massive sulphide deposits and prospects in the area, and 2) to extend this insight into less understood areas. The 2000 field season was directed toward this latter goal with new mapping in areas south and east of the core of the Finlayson Lake district. Parts of Klatsa River (105H/3), 'Tuchitua River North' (105H/4) and Money Creek (105H/5) areas were mapped at 1:50 000 scale (Figs. 1, 2; Murphy, 2000a, b, c). This report documents the stratigraphy of Yukon-Tanana Terrane in this area and outlines areas underlain by volcanic rocks with potential for volcanogenic massive sulphide deposits. A new interpretation of the nature of ultramafic rocks in the area is also presented, one with implications for the exploration for Ni-Cu-PGM deposits. Finally, the setting of eclogite-facies metamorphic rocks in Klatsa River (105H/3) area is addressed.

PREVIOUS WORK

The geology of Yukon-Tanana Terrane in Frances Lake map area has not been documented at scales better than 1:250 000. Blusson (1966a, b, 1967) reported on 1:250 000-scale mapping of the Frances Lake map area, including the southwest corner. Mortensen (1983) and

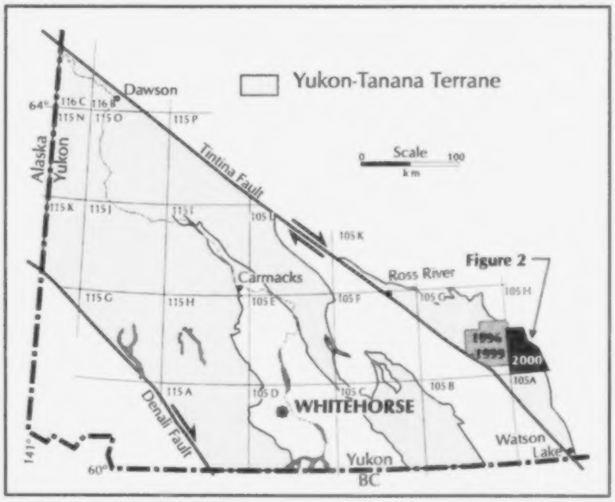
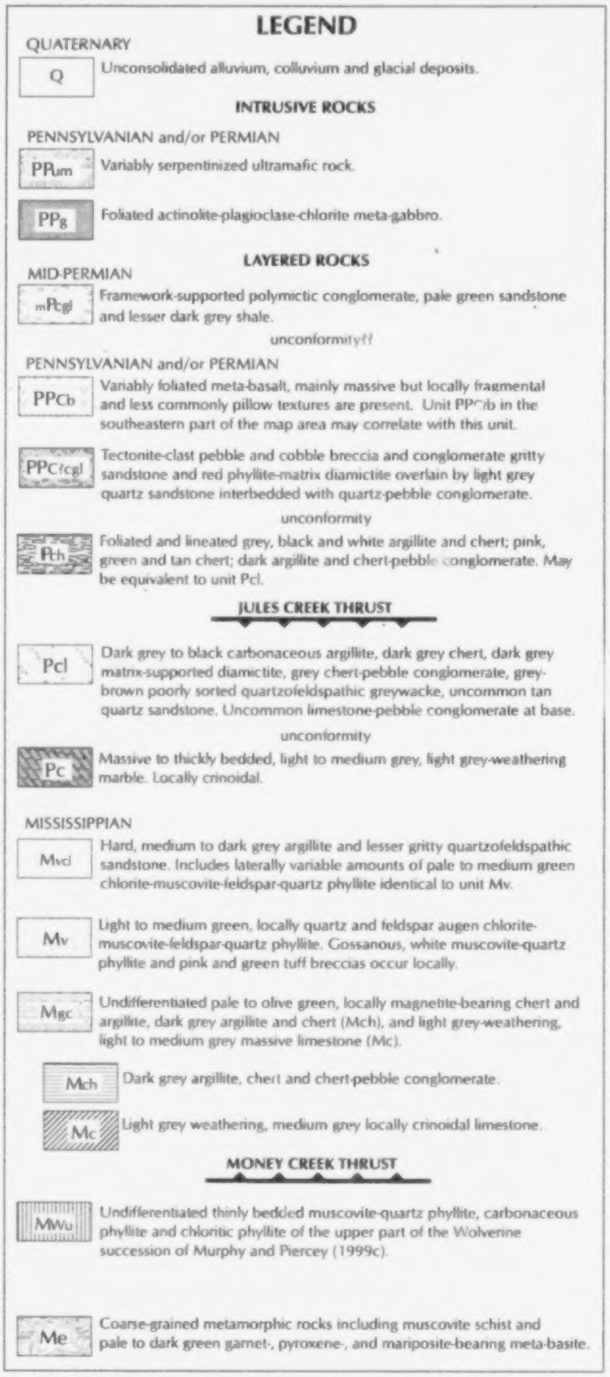


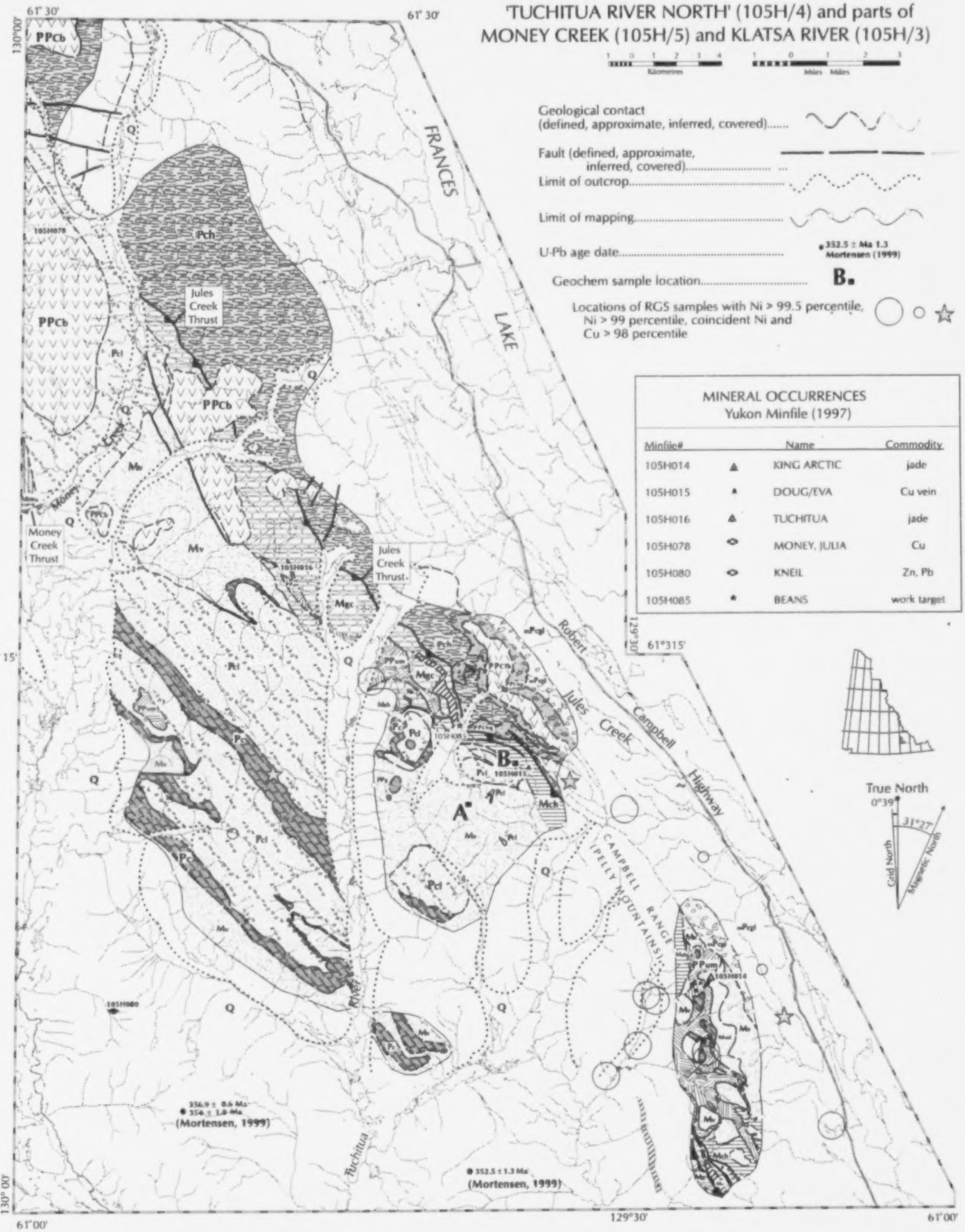
***Figure 1.** Map of southern Yukon showing location of Figure 2 with respect to distribution of Yukon-Tanana Terrane.*



LEGEND

QUATERNARY	
Q	Unconsolidated alluvium, colluvium and glacial deposits.
INTRUSIVE ROCKS	
PENNSYLVANIAN and/or PERMIAN	
PPum	Variably serpentinized ultramafic rock.
PPg	Foliated actinolite-plagioclase-chlorite meta-gabbro.
LAYERED ROCKS	
MID-PERMIAN	
mPcgl	Framework-supported polymictic conglomerate, pale green sandstone and lesser dark grey shale.
unconformity??	
PENNSYLVANIAN and/or PERMIAN	
PPCb	Variably foliated meta-basalt, mainly massive but locally fragmental and less commonly pillow textures are present. Unit PPCb in the southeastern part of the map area may correlate with this unit.
PPC?cgl	Tectonite-clast pebble and cobble breccia and conglomerate gritty sandstone and red phyllite-matrix diamictite overlain by light grey quartz sandstone interbedded with quartz-pebble conglomerate.
unconformity	
Pch	Foliated and lineated grey, black and white argillite and chert; pink, green and tan chert; dark argillite and chert-pebble conglomerate. May be equivalent to unit Pcl.
JULES CREEK THRUST	
Pcl	Dark grey to black carbonaceous argillite, dark grey chert, dark grey matrix-supported diamictite, grey chert-pebble conglomerate, grey-brown poorly sorted quartzofeldspathic greywacke, uncommon tan quartz sandstone. Uncommon limestone-pebble conglomerate at base.
unconformity	
Pc	Massive to thickly bedded, light to medium grey, light grey-weathering marble. Locally crinoidal.
MISSISSIPPIAN	
Mvcl	Hard, medium to dark grey argillite and lesser gritty quartzofeldspathic sandstone. Includes laterally variable amounts of pale to medium green chlorite-muscovite-feldspar-quartz phyllite identical to unit Mv.
Mv	Light to medium green, locally quartz and feldspar augen chlorite-muscovite-feldspar-quartz phyllite. Gossanous, white muscovite-quartz phyllite and pink and green tuff breccias occur locally.
Mgc	Undifferentiated pale to olive green, locally magnetite-bearing chert and argillite, dark grey argillite and chert (Mch), and light grey-weathering, light to medium grey massive limestone (Mc).
Mch	Dark grey argillite, chert and chert-pebble conglomerate.
Mc	Light grey weathering, medium grey locally crinoidal limestone.
MONEY CREEK THRUST	
MWu	Undifferentiated thinly bedded muscovite-quartz phyllite, carbonaceous phyllite and chloritic phyllite of the upper part of the Wolverine succession of Murphy and Piercey (1999c).
Me	Coarse-grained metamorphic rocks including muscovite schist and pale to dark green garnet-, pyroxene-, and mariposite-bearing meta-basite.

***Figure 2** (above and on next page). Simplified compilation map of new geological mapping in southwestern Frances Lake area (Murphy, 2000a,b,c). Regional stream-sediment samples (Hornbrook and Friske, 1988), with anomalous Ni and Cu contents, are superimposed on the geology in the southeastern part of the area.*


'TUCHITUA RIVER NORTH' (105H/4) and parts of
MONEY CREEK (105H/5) and KLATSA RIVER (105H/3)
Kilometres
Miles
Geological contact (defined, approximate, inferred, covered)
Fault (defined, approximate, inferred, covered)
Limit of outcrop
Limit of mapping
U-Pb age date
352.5 ± Ma 1.3 Mortensen (1999)
Geochem sample location
B.
Locations of RGS samples with Ni > 99.5 percentile, Ni > 99 percentile, coincident Ni and Cu > 98 percentile
61° 30'
61° 30'
130°00'
61° 15'
61°315'
129°30'
130° 00'
61°00'
129°30'
61°00'
FRANCES
LAKE
Robert
Campbell
Highway
Jules
Creek
Money
Creek
Jules Creek Thrust
Money Creek Thrust
CAMPBELL RANGE (PELLY MOUNTAINS)
Tuchitua
River
PPCb
Pch
Pcl
Mv
Mgc
Mch
PPum
Pd
Pc
Q
mPcgl
105H078
105H016
105H085
105H015
105H014
105H080
A
B
336.9 ± 0.6 Ma
354 ± 1.0 Ma
(Mortensen, 1999)
352.5 ± 1.3 Ma
(Mortensen, 1999)
True North
0°39'
31°27'
Grid North
Magnetic North

MINERAL OCCURRENCES
Yukon Minfile (1997)

Minfile#		Name	Commodity
105H014	▲	KING ARCTIC	jade
105H015	•	DOUG/EVA	Cu vein
105H016	△	TUCHITUA	jade
105H078	⬭	MONEY, JULIA	Cu
105H080	⬭	KNEIL	Zn, Pb
105H085	★	BEANS	work target

Figure 2 continued.

Mortensen and Jilson (1985) mapped this part of Frances Lake map area in the course of regional reconnaissance of Yukon-Tanana Terrane north of the Tintina Fault. Mortensen (1983, 1992, 1999) reported U-Pb age dates from meta-volcanic and meta-plutonic rocks from this area. Erdmer et al. (1998) reported on investigations of eclogite facies metamorphic rocks in this area.

Small parts of Frances Lake map area are included in a 1:100 000 compilation (Murphy and Piercey, 1999a) of recent mapping in the Finlayson Lake massive sulphide district (Murphy, 1997; Murphy and Piercey, 1999b). This work has shown that most of the deposits of the district (Kudz Ze Kayah, GP4F and Wolverine) occur in two felsic meta-volcanic rock units of Devono-Mississippian and

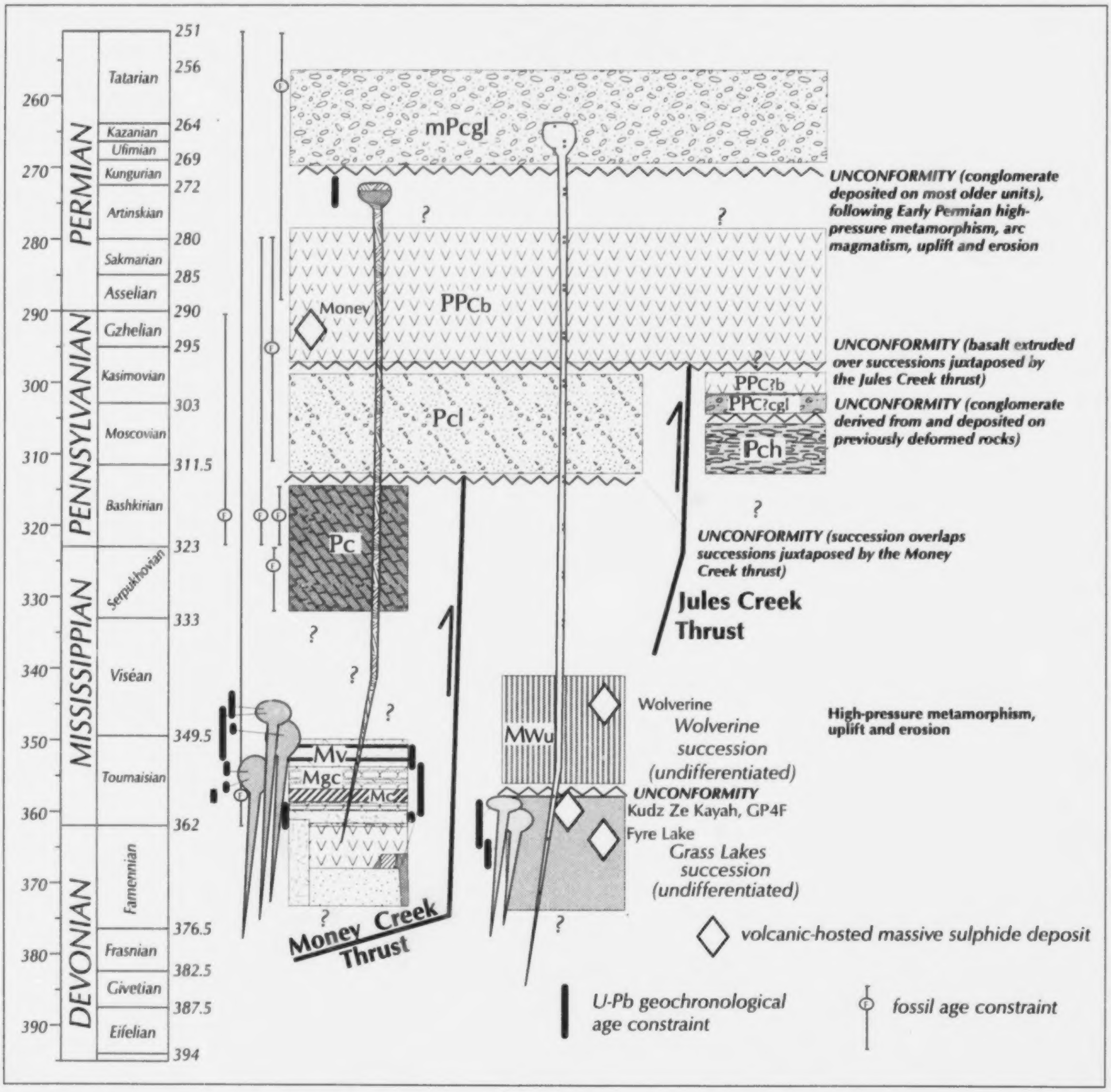

PERMIAN
PENNSYLVANIAN
MISSISSIPPIAN
DEVONIAN
Tatarian
Kazanian
Ufimian
Kungurian
Artinskian
Sakmarian
Asselian
Gzhelian
Kasimovian
Moscovian
Bashkirian
Serpukhovian
Viséan
Tournaisian
Famennian
Frasnian
Givetian
Eifelian
260
270
280
290
300
310
320
330
340
350
360
370
380
390
251
256
264
269
272
280
285
290
295
303
311.5
323
333
349.5
362
376.5
382.5
387.5
394
mPcgl
UNCONFORMITY (conglomerate deposited on most older units), following Early Permian high-pressure metamorphism, arc magmatism, uplift and erosion
?
?
Money
PPCb
UNCONFORMITY (basalt extruded over successions juxtaposed by the Jules Creek thrust)
PPC?b
PPC?cgl
UNCONFORMITY (conglomerate derived from and deposited on previously deformed rocks)
Pch
Pcl
?
Pc
UNCONFORMITY (succession overlaps successions juxtaposed by the Money Creek thrust)
Jules Creek Thrust
?
?
?
Mv
Mgc
Mc
MWu
Wolverine
Wolverine succession (undifferentiated)
UNCONFORMITY
Kudz Ze Kayah, GP4F
Fyre Lake
Grass Lakes succession (undifferentiated)
High-pressure metamorphism, uplift and erosion
?
Money Creek Thrust
?
volcanic-hosted massive sulphide deposit
U-Pb geochronological age constraint
fossil age constraint

Figure 3. *Summary of stratigraphy and stratigraphic relationships in southwestern Frances Lake area. Legend same as in Figure 2.*

early Mississippian age that likely formed in an ensialic back-arc region (Murphy and Piercey, 1999c; Piercey et al., 2000, in review). This region was overthrust from the south-southwest along the Money Creek thrust by a sequence of rocks including coeval mafic to felsic meta-volcanic rocks with geological and geochemical characteristics of arc volcanic rocks. The back-arc strata trend southeastwardly out of the area of the known deposits; however, the Money Creek thrust trends eastwardly where last mapped and appears to truncate these highly prospective back-arc strata. A major goal of the 2000 field season was to determine the extent of these rocks in the Frances Lake area.

YUKON-TANANA TERRANE IN SW FRANCES LAKE AREA

Yukon-Tanana Terrane in southwestern Frances Lake area consists of several fault- or unconformity-bound successions (Figs. 2 and 3). The most extensive succession is found in the Money Creek thrust sheet. Rocks of the Money Creek thrust sheet are bounded by the Money Creek thrust and unconformably overlying rocks on the north, the Jules Creek thrust on the northeast, and extend out of the area to the south and west. A succession of dark chert and meta-clastic rocks unconformably overlies the Money Creek thrust sheet. A similar, possibly correlative, chert-rich succession occurs in the footwall of the Jules Creek thrust where it is overlain unconformably by a succession of coarse, post-orogenic meta-clastic rocks and meta-basalt. The Campbell Range basalt and lesser chert overlies, probably unconformably, different units belonging to all of these successions. The easternmost succession, extending into the broad Frances Lake lowlands, consists primarily of a distinctive mid-Permian to possibly Triassic polymictic conglomerate and sandstone unit that is inferred, based on clast composition, to unconformably overlie the other successions. This succession lies between rocks of Yukon-Tanana Terrane and ancestral North America, making it an important key to the understanding of the relationship between these elements. In addition to meta-sedimentary and meta-volcanic rocks, mafic and serpentinized ultramafic meta-plutonic rocks occur in all but the latter succession (except as clasts).

MONEY CREEK THRUST SHEET

The Money Creek thrust was originally documented in the southern part of Finlayson Lake area (Murphy and Piercey, 1999a, b, 2000; Piercey and Murphy, 2000; the thrust sheet includes the Money and North Klippe of Tempelman-Kluit (1979) and its trace incorporates the trace of a thrust inferred by Mortensen and Jilson (1985)). In southern Finlayson Lake area, the thrust sheet is made up of Devono-Mississippian mafic and felsic meta-volcanic rocks, mafic and ultramafic meta-plutonic rocks and lesser meta-chert, dark phyllite and limestone; these rocks are intruded by variably foliated early Mississippian hornblende-bearing granitic meta-plutonic rocks. Hanging-wall rocks have been traced eastwardly into southwestern Wolverine Lake area (105G/8, Murphy and Piercey, 1999b) and northeastern Waters Creek area (105G/1; Murphy and Piercey, 1999a) where they disappear into the broad valley occupied in part by Money Creek and in part by an un-named tributary to the Tuchitua River. The easterly or eastward trend of the rocks in the thrust sheet cuts across the southeastward trend of the early Mississippian and older Grass Lakes and Wolverine successions in the footwall.

Rocks east of this broad valley resemble the hanging-wall rocks in southern Wolverine Lake area. They consist of a succession comprising a lower unit of meta-chert, dark meta-clastic rocks and limestone (units Mgc, Mch and Mc); intermediate to felsic meta-volcanic rocks (unit Mv); and a laterally continuous, crinoidal limestone (unit Pc). The oldest rocks in the Money Creek thrust sheet in Frances Lake map area occur along the eastern edge of the sheet, along the Jules Creek thrust (Fig. 2). Unit Mgc is composed primarily of locally magnetite-bearing, laminated pale green and tan chert and waxy tan and greenish-grey argillite (Fig. 4). The presence of magnetite

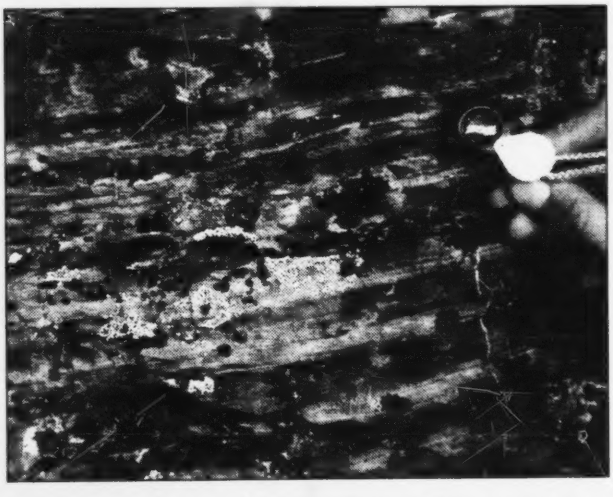


***Figure 4.** Unit Mgc: pale green chert and lesser tan chert and argillite.*

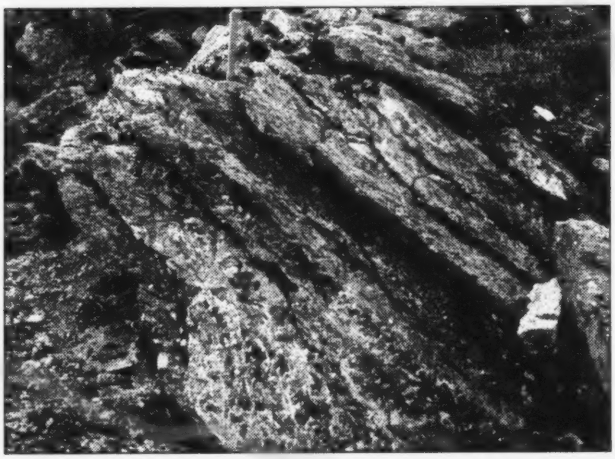


Figure 5. Unit Mc: marble and garnet diopside skarn in unit Mc along contact with ultramafic rocks.

and the lack of visible radiolaria and ribbon bedding typical of radiolarian chert suggests that this unit is not of biogenic origin and likely is a volcanogenic deposit, possibly a distal tuff. With pale green chert above and below it, unit Mc, a variably thick, pale-grey-weathering, medium grey limestone, occurs as a member within unit Mgc. Unit Mc locally is metamorphosed to coarse-grained diopside-epidote rock along contacts with ultramafic rocks (Fig. 5). Dark chert, argillite and lesser quartzite of unit Mch (Fig. 6) overlies unit Mgc north of Jules Creek; southeast of Jules Creek, unit Mch appears to be laterally equivalent to unit Mgc. Intermediate and locally felsic meta-igneous rocks, either sub-volcanic feeders to unit Mv or meta-volcanic rocks, occur locally in units Mgc, Mc and Mch.

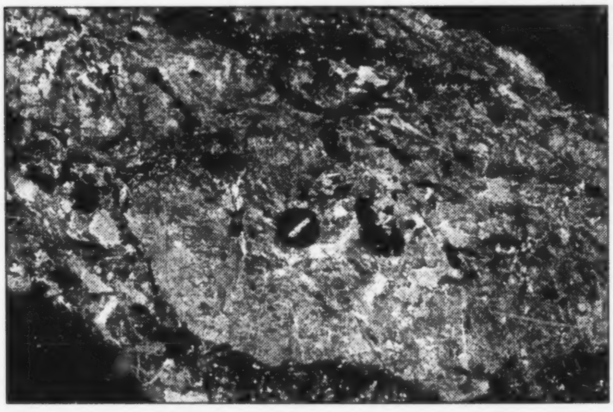


Figure 6. Unit Mch: medium grey siliceous argillite and quartzite.

Units Mgc, Mc and Mch are indirectly constrained to be early Mississippian in age. They are overlain by volcanic rocks of unit Mv from which an early Mississippian U-Pb age date was obtained (Mortensen, 1999; see below). In the western part of the Money Creek thrust sheet, similar pale green chert and dark argillite overlies mafic and lesser felsic meta-volcanic rocks of Devono-Mississippian age (Murphy and Piercey, 2000).

Dark chert and meta-clastic rocks of unit Mch are overlain by intermediate to felsic meta-volcanic rocks of unit Mv. This unit extends southward from Money Creek to south of Jules Creek. It was also found in Klatsa River area (105H/3) and likely continues southward into Watson Lake area (105A; Mortensen and Jilson, 1985). Unit Mv comprises mainly medium green chloritic phyllite with less common muscovite-quartz phyllite (Fig. 7a). Quartz and feldspar augen occur locally in the chloritic phyllite

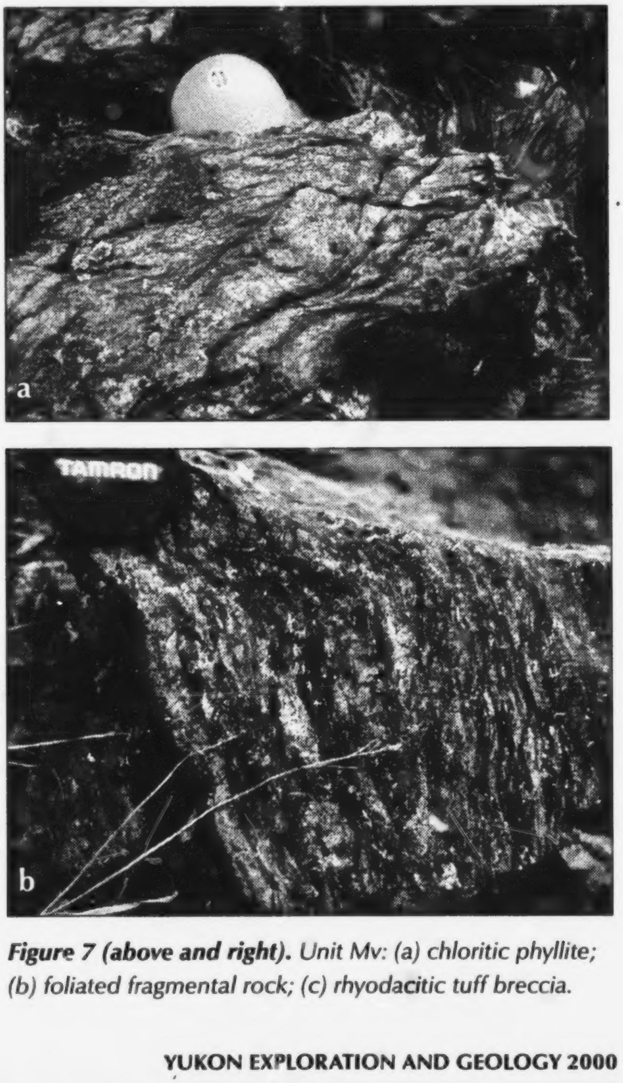


***Figure 7 (above and right).** Unit Mv: (a) chloritic phyllite; (b) foliated fragmental rock; (c) rhyodacitic tuff breccia.*

and fragmental textures are locally well preserved (Fig. 7b). In its western outcrop belt in 'Tuchitua River North' area, unit Mv also contains foliated pink and whitish-green rhyodacitic tuff breccia (Fig. 7c). Pyrite is locally abundant in chloritic phyllite and muscovite-quartz phyllite; the latter commonly host laterally extensive gossans south and east of Jules Creek. The age of unit Mv is constrained by one U-Pb age date of 352.5 ± 1.3 Ma obtained from samples of rhyodacitic tuff breccia (Mortensen, 1999).

A laterally extensive limestone unit (unit Pc) overlies unit Mv, with sharp contact (Figs. 2, 8a). Unit Pc consists primarily of foliated and recrystallized, light grey-weathering, medium grey limestone. Randomly oriented crinoid fragments and disarticulated columnals occur in many outcrops suggesting that the unit is bioclastic in origin (Fig. 8b). Intraformational breccia also occurs locally. Bedding is typically massive and thick (m-scale); locally decimetre-scale bands of white to tan quartz of probable replacement origin occur parallel to a compositional layering that is likely bedding. The age of unit Pc is loosely constrained in this area by one early Pennsylvanian to Early Permian conodont collection (Bashkirian-Sakmarian; M. Orchard and J.K. Mortensen, *in:* Poulton et al., 1999). Similar limestone in Watson Lake area contains Bashkirian (early Pennsylvanian) conodonts (Poulton et al., 1999) and in Finlayson Lake area, Serpukhovian conodonts (late Mississippian; J. Hunt, pers. comm., 1998; identification by M. Orchard). A late Mississippian to early Pennsylvanian age is therefore favoured based on the inferred ages of overlying rocks discussed below.

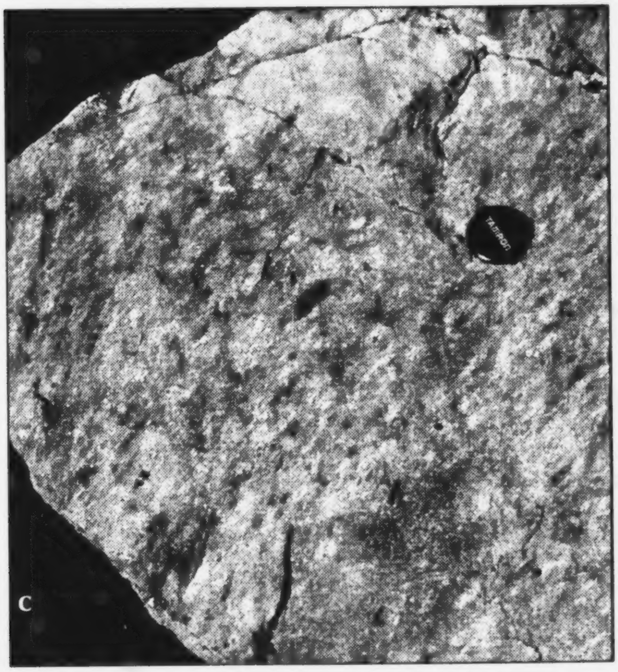


***Figure 7** continued.*

DARK CHERT AND CLASTIC UNIT (Pcl)

The rock units of the Money Creek thrust sheet and the Wolverine succession in the footwall of the Money Creek thrust are overlain by a regionally extensive heterogeneous unit of dark chert, meta-clastic rocks and rare limestone (unit Pcl). Unit Pcl consists primarily of locally sooty, probably carbonaceous dark argillite with laterally and vertically variable amounts of thin- to medium-bedded grey and grey-green chert (Fig. 9a) and a variety of meta-clastic rocks. Pink and green argillite and ribbon chert occur locally in the lower part of the unit, with beds of light grey-weathering, medium grey limestone up to 5 m thick and rare fine-grained green

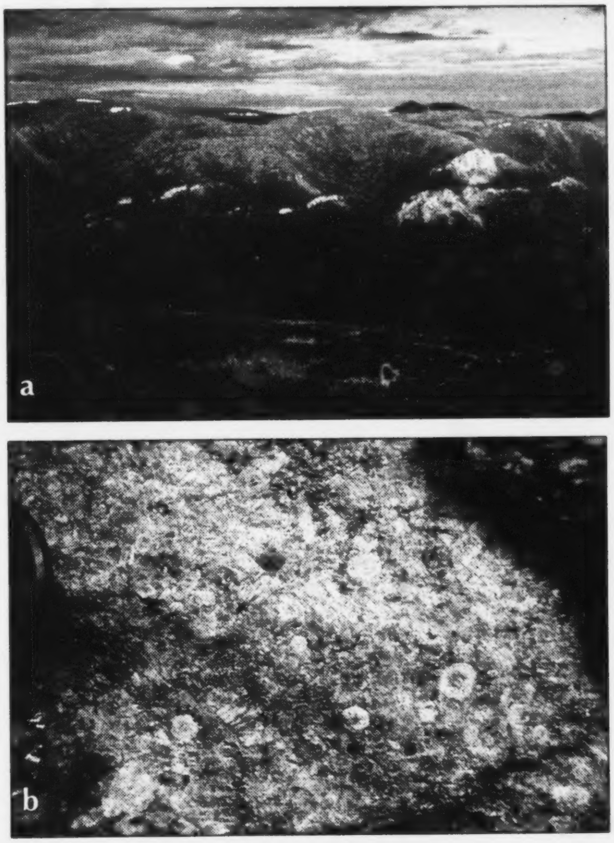


***Figure 8(above).** Unit Pc: (a) laterally continuous exposures; (b) bioclastic crinoid fragments.*

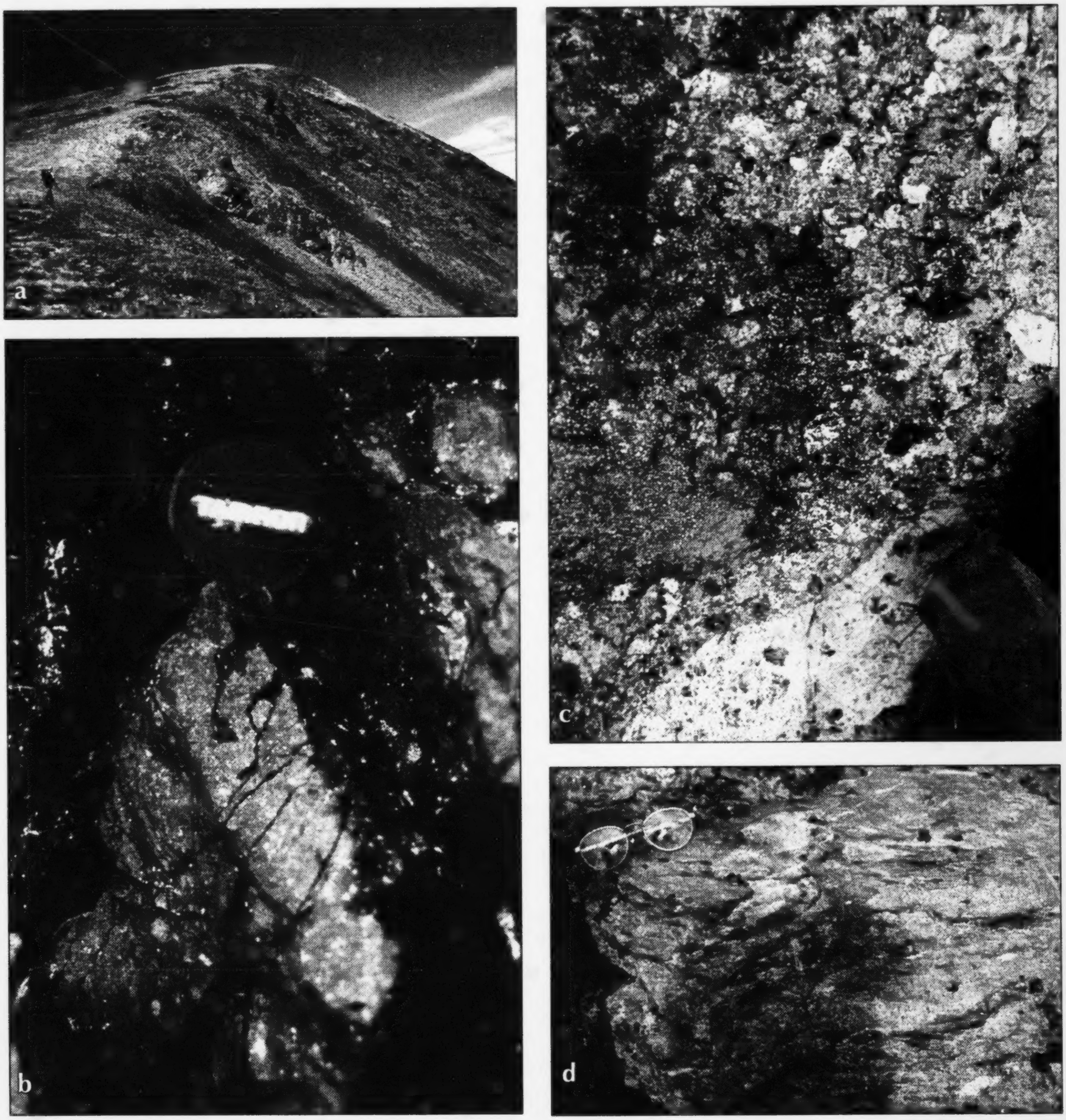


Figure 9. *Unit Pcl: (a) chert and argillite; (b) greywacke; (c) volcano-lithic pebble conglomerate; (d) sand-matrix diamictite; (e) argillite-matrix diamictite; (f) limestone-clast conglomerate.*

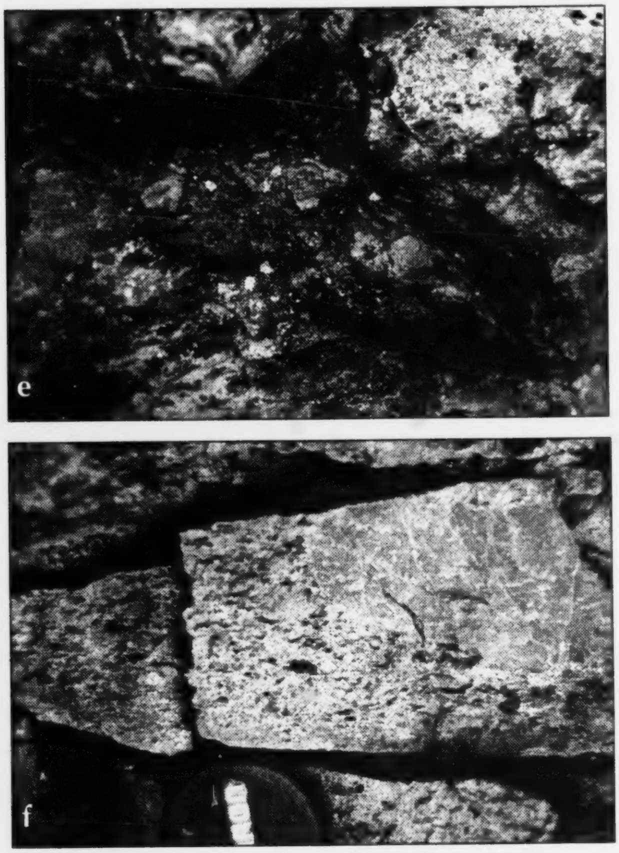


***Figure 9** continued.*

siliceous rock of possible tuffaceous origin. Common coarse-grained meta-clastic rocks include mottled grey-white chert-pebble conglomerate, pebble to cobble diamictite, greenish-grey quartzofeldspathic and volcano-lithic greywacke (Fig. 9b) and pebble conglomerate (Fig. 9c), and rarely tan clean quartz sandstone. Two types of diamictite have been observed, a sand-matrix variety where pebbles and cobbles of intermediate to felsic meta-volcanic rock and volcano-lithic greywacke with dark argillite clasts float in a greywacke matrix (Fig. 9d), and an argillite-matrix variety where the same types of clasts float in a matrix of locally sooty, dark grey argillite (Fig. 9e). A conglomerate consisting of pebbles to cobbles of medium grey limestone and tan quartz identical to the replacement quartz in unit Pc occurs locally near the base of the unit (Fig. 9f).

The basal contact of unit Pcl is inferred to be a profound regional unconformity. The unit overlies different rock units in different areas, mainly sitting on unit Pc but also lying directly on unit Mv. Upward variation in conglomerate clast compositions suggest progressively deeper erosion of underlying rocks; conglomerate near the base of the unit contains clasts of limestone and replacement silica identical to unit Pc and the youngest exposed conglomerate is full of volcano-lithic detritus similar to unit Mv. Sandstone and greywacke contain distinctive smoky grey quartz grains throughout that resemble quartz phenocrysts in unit Mv and older volcanic rocks of the Money Creek thrust sheet. Unit Pcl also overlies the Wolverine succession in the footwall of the thrust. As the dark clastic unit is apparently not offset by the thrust, thrusting therefore pre-dates this unit.

The age of unit Pcl is indirectly and loosely constrained as Pennsylvanian. It overlies unit Pc of late Mississippian to early Pennsylvanian age and underlies the Campbell Range basalt, which has mid-Pennsylvanian to Early Permian radiolaria (T. Harms *in:* Plint and Gordon, 1997, p. 124; see below). Displacement on the Money Creek thrust is therefore constrained to be Pennsylvanian in age.

FOOTWALL OF JULES CREEK THRUST

Although the Jules Creek thrust is inferred to extend at least as far north as Money Creek, rocks in its footwall are only reasonably well exposed on ridge networks northwest and southeast of Jules Creek. Northwest of this area, the only area of significant exposure occurs north of Money Creek. Elsewhere, exposure is poor except for isolated hilltops that are underlain by outliers of Campbell Range basalt. The footwall succession consists of a lower unit similar to unit Pcl (unit Pch) and an unconformably overlying sequence of meta-conglomerate (PPC?cgl) and meta-basalt (PPC?b).

Unit Pch

Underlying generally poorly exposed ground from the northern edge of Money Creek area (105H/5) to the ridge northwest of Jules Creek, unit Pch is not well documented. At the northern edge of Money Creek area, the unit comprises tan, pink and green chert and lesser argillite and a poorly exposed underlying member of dark argillite, chert and chert-pebble conglomerate. Immediately north of Money Creek, the unit comprises dark argillite, thin-bedded to massive greyish-green chert, and less commonly mottled grey and white chert-pebble conglomerate (Fig. 10a), meta-basalt or diabase, and rarely medium-grained greywacke and pods of crinoidal limestone. Between Money Creek and the ridge northwest of Jules Creek, pink, green and tan chert and dark argillite have been observed. On either side of Jules Creek, the unit also comprises greyish white siliceous phyllite and dark argillite with rare brown dolomitic siltstone (Fig. 10b). The thickness of unit Pch is not known.

The age and correlation of unit Pch are not known. The unit resembles unit Pcl but lacks the distinctive diamictite units, and volcano-lithic detritus is so far limited to the one greywacke bed north of Money Creek. As unit Pch occurs on the opposite side of the Jules Creek thrust from unit Pcl, they may be distal facies equivalents.

Unit PPc?cgl

Unit Pch is unconformably overlain by coarse-grained meta-clastic rocks of unit PPc?cgl. The basal strata of unit

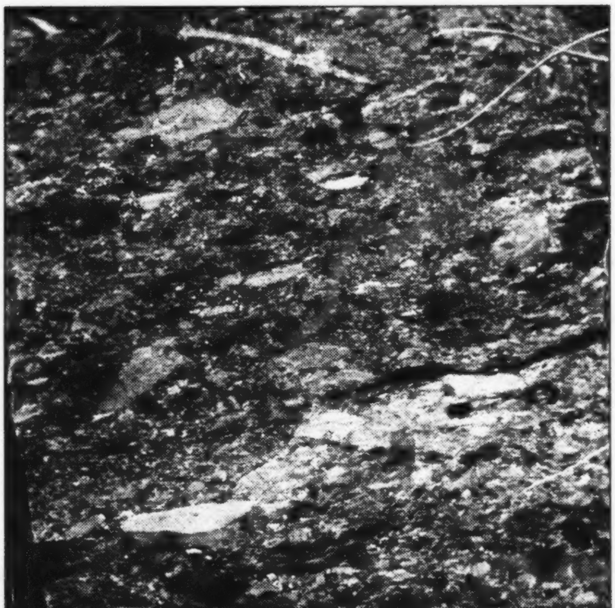


Figure 10. *Unit Pch: (a) chert-pebble conglomerate; (b) dolomitic siltstone with net-textured veins.*

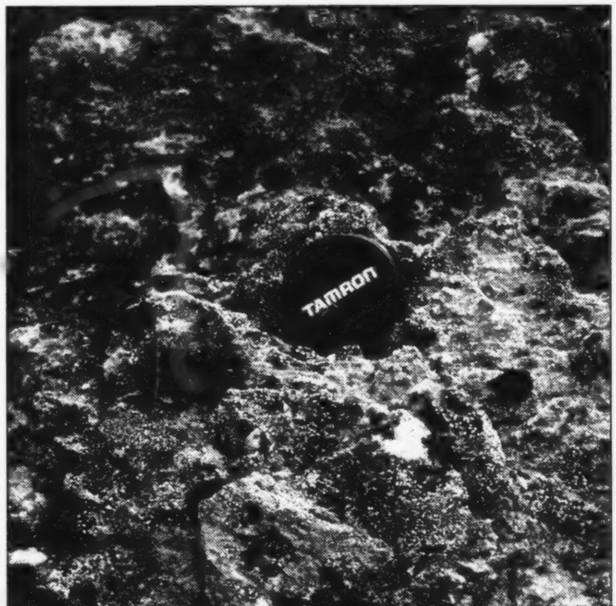


Figure 11. *Unit PPc?cgl: (a) tectonite-clast conglomerate; (b) massive, locally cherty carbonate interval within coarse-grained clastic rocks.*

PPC?cgl consists of weakly foliated grey pebble- to cobble-breccia made up of randomly oriented angular clasts of foliated and lineated rocks from unit Pch (Fig. 11a). Over a few metres, these strata pass into pink ferruginous pebbly breccia, sandstone and argillite and khaki to brown sandstone and conglomerate with angular siliceous phyllite clasts and rounded clasts of white quartz. Local float of quartz-eye felsic meta-volcanic rock occurs in this part of the section but was never found in outcrop. Further up section, sandstone and argillite turn grey and are intercalated with tan-black cherty carbonate and calcareous chert (Fig. 11b).

The age of unit PPC?cgl is unconstrained. If the underlying rocks correlate with unit Pcl, and the overlying rocks correlate with unit PPCb (see next section), then unit PPC?cgl would be late Pennsylvanian. The unconformity at the base of unit PPC?cgl would therefore reflect uplift and erosion following a late Pennsylvanian regional deformation.

Unit PPC?b

Meta-basalt of unit PPC?b overlies the meta-clastic rocks of unit PPC?cgl with sharp, apparently conformable contact. Unit PPC?b comprises variably foliated, variably calcareous greenschist and greenstone. On the eastern limb of the syncline that encloses unit PPC?b on both sides of Jules Creek, the unit comprises chloritic phyllite with pods and lenses of calcite. The unit is less foliated up section and is a massive greenstone. Calcareous pods and lenses occur at this stratigraphic level as well.

The age of unit PPC?b is not directly constrained. It is lithologically similar to unit PPCb, which is likely late Pennsylvanian, or Early Permian in age (see below).

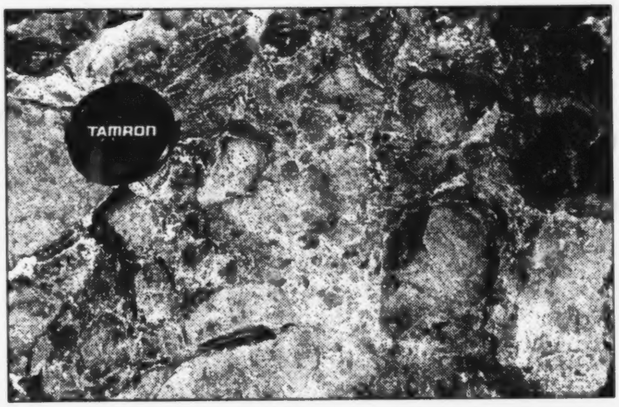


Figure 12. *Unit PPCb: fragmental texture in basalt below contact with tan chert.*

CAMPBELL RANGE BASALT (UNIT PPCb)

The Campbell Range basalt is found in Money Creek area (105H/5) on either side of Money Creek. Northwest of Money Creek, the unit crops out as a continuous slab across the northeastern part of Wolverine Lake area (105G/8; Murphy and Piercey, 1999b,c). Southwest of Money Creek it occurs in a few isolated hilltop exposures. The unit consists mainly of unfoliated to weakly foliated light- to dark-green-weathering, dark green basalt and rare pink and green chert. Basalt is mainly massive although fragmental textures (Fig. 12) and pillows occur locally.

The Campbell Range basalt is inferred to overlie a profound unconformity. It is less foliated and not folded to the same extent as underlying rocks. Furthermore, it overlies different rock units in different parts of the map area. It overlies unit Pcl in Wolverine Lake area (105G/8) and the western part of Money Creek area (105H/5), and is inferred to overlie units Mv, Mch and Mgc in southwestern Money Creek area and unit Pch in the footwall of the Jules Creek thrust in northern and central Money Creek area. Hence, it appears to post-date motion on the Jules Creek thrust. However, if unit PPC?b correlates with the Campbell Range basalt, an inconsistency arises as Unit PPC?b is overthrust along the Jules Creek thrust. The relation between the Campbell Range basalt and the Jules Creek thrust is not confidently documented so the correlation with unit PPC?b remains uncertain.

The Campbell Range basalt is probably late Pennsylvanian to early Early Permian. It is interbedded near its base with pink radiolarian chert from which early Pennsylvanian to Early Permian radiolaria have been obtained (Atokan-Wolfcampian; T. Harms, *in:* Plint and Gordon, 1997, p. 124) and it is intruded by a ca. 274 Ma leucogabbro in McEvoy Lake area (105G/9; Mortensen and Murphy, unpublished data). However, it overlies unit Pcl, which is younger than Bashkirian (early Pennsylvanian).

POLYMICTIC CONGLOMERATE (mPcgl)

Southeastward from near 99 Mile Creek, the eastern flank of the Campbell Range is underlain by a unit of foliated, poorly sorted, mottled grey-green, polymictic pebble- to boulder-conglomerate, greywacke and medium grey argillite. At the five stations where this unit was observed, conglomerate occurs in massive beds at least 2 m thick with interbedded coarse sandstone and argillite in 10- to 30-cm-thick beds. The proportion of conglomerate to sandstone and argillite could not be determined except at one location where conglomerate made up about 60% of the outcrop, greywacke, 30% and dark argillite, 10%.

Conglomerate clast content varies along strike. At one locality along the Campbell Highway (470192E, 6791538N), clasts include grey muscovite-quartz phyllite, chloritic phyllite, massive porphyritic basalt/andesite, aphyric massive basalt similar to the Campbell Range basalt, round white quartz pebbles, single crystal feldspars, and angular quartz sand in the matrix (Fig. 13a). At an isolated location in the Campbell Range in Klatsa River map area (105H/3), clasts are mainly meta-sedimentary including black chert, green chert, tan chert, grey carbonate, and muscovite-quartz phyllite (Fig. 13b). A similar conglomerate on strike in Watson Lake area comprises clasts of massive greenstone, gabbro, anorthosite, serpentinite, quartzite, quartz-mica schist, amphibolite, eclogite and blueschist with Permian cooling ages, massive mid-Permian dacite and andesite (Mortensen et al., 1997, 1999).

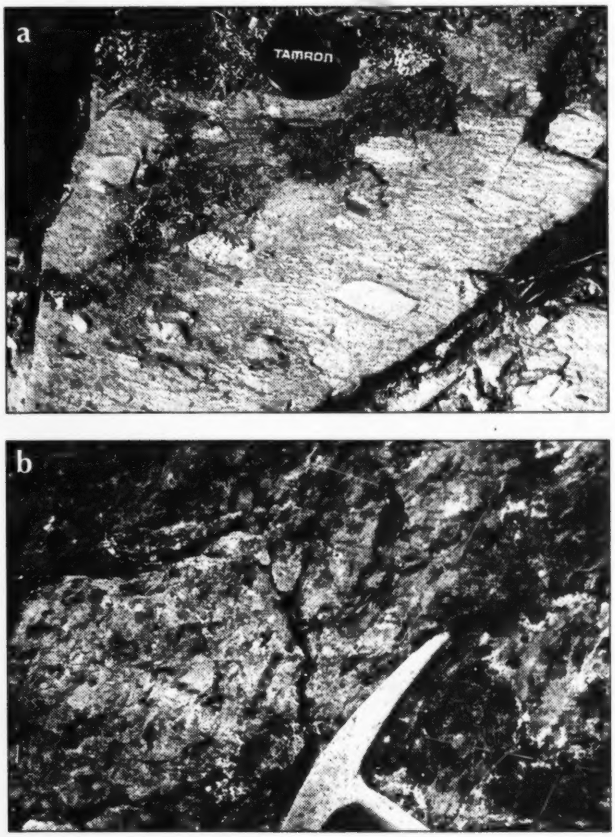


Figure 13. *Unit mPcgl: (a) polymictic conglomerate in exposure along Campbell Highway; (b) limestone and chert clasts in an isolated exposure of polymictic conglomerate about 5 km south of King Arctic jade mine.*

The contact of the conglomerate with Yukon-Tanana Terrane rocks to the west is not exposed. The conglomerate is adjacent to a number of different rock units along its trend, implying either a fault or an unconformity. As clasts in the conglomerate include many of the rock types of Yukon-Tanana Terrane, the original contact was likely an unconformity; however, the current contact may be a fault. On the northeast, the conglomerate is in contact with a massive tan chert. This contact has been crossed in only one locality and its nature has not been determined. Neither the age nor the paleogeographic affinity of the chert is known.

The age of the conglomerate in Frances Lake area is indirectly constrained to be Permian, possibly ranging into the Triassic. If the basalt clasts in the conglomerate were derived from the late Pennsylvanian to early Early Permian Campbell Range basalt then the conglomerate must be younger than that. The conglomerate resembles and is on strike with a polymictic conglomerate in Watson Lake area that is likely mid-Permian in age based on:
1) Permian conodonts have been extracted from argillaceous limestone beds in the conglomerate unit near Simpson Lake in Watson Lake area (J.K Mortensen, pers. comm., 1999; identification by M.J. Orchard, report MJO-1998-5), 2) metamorphic and dacite clasts have mid-Permian to earliest Triassic K-Ar mineral dates (Mortensen et al., 1997, 1999), and 3) felsic meta-volcanic rocks in the same sequence have mid-Permian U-Pb ages (ca. 264 Ma, J.K. Mortensen, pers. comm., 2000). However, the Watson Lake and Frances Lake conglomerates resemble a polymictic conglomerate near Faro with limestone interbeds containing Triassic conodonts (Tempelman-Kluit, 1979; Mortensen and Jilson, 1985; Mortensen et al., 1997, 1999). A mid-Permian age for the conglomerate in Frances Lake area is almost certain based on the on-strike continuity with the dated conglomerate in the Watson Lake area; however, an age ranging into the Triassic cannot be ruled out.

ECLOGITE FACIES METAMORPHIC ROCKS (Me)

An isolated exposure of coarse-grained metamorphic rocks, inferred to have been exposed to eclogite facies conditions, occurs in Klatsa River area (105H/3; Mortensen and Jilson, 1985; Erdmer et al., 1998). Standing in distinct contrast to nearby greenschist grade meta-sedimentary and meta-volcanic rocks, these rocks comprise light-brown-weathering, light brown to rusty coarse-grained white mica quartz schist and medium green massive to weakly foliated garnet amphibolite locally containing a pale green mineral resembling clinopyroxene (samples await thin section analysis). Erdmer et al. (1998) reported that retrograde minerals predominate in the rock and no primary peak metamorphic phases remain; garnet is largely replaced by clinozoisite and chlorite and no primary clinopyroxenes were noted. The geochemical character of meta-basite from this locality is that of normal mid-ocean ridge basalt (Creaser et al., 1999) with hints of an arc influence (S. Piercey, pers. comm., 2000).

The setting of these rocks with respect to nearby rocks remains unresolved. They occur at the end of a ridge overlying weakly metamorphosed dark grey argillite, gritty chert-quartz sandstone and pebble conglomerate, and diamictite correlated with unit Pcl, which, in turn, overlie pale green chert and limestone of units Mgc and Mc, respectively. Massive chert and chert-pebble conglomerate, possibly of unit Pcl, are found in isolated outcrops to the west and up structural section from the schist. Neither the upper nor lower contacts of the coarse-grained schist are exposed. Similar coarse-grained metamorphic rocks occur across a 50 m interval along the next ridge to the north; their extent farther to the north or south could not be established.

The age of the protolith of these coarse-grained metamorphic rocks is constrained to be pre-early Mississippian. A 344 ± 1 Ma Ar^{40}/Ar^{39} plateau cooling date (346 ± 1 Ma integrated date) was obtained from white mica extracted from samples from this locality (Erdmer et al., 1998), implying peak metamorphism before this time and an even older protolith age. On the basis of geochemical similarity, Creaser et al. (1999) suggested that the protoliths of eclogite from the Campbell Range and Stewart Lake localities might correlate with geochemically similar rocks in the 365-360 Ma Fire Lake meta-basite unit (unit 2 of Murphy, 1998; unit DMF of Murphy and Piercey, 1999a).

ULTRAMAFIC AND MAFIC INTRUSIONS (PPum)

Numerous bodies of serpentinized ultramafic rock, gabbro and diabase, ranging in size from a few metres wide to several square kilometres in area, occur throughout the Campbell Range in Frances Lake area. The largest one, in Klatsa River area (105H/3), hosts the King Arctic jade mine (Yukon MINFILE #105H 014). Ultramafic rocks typically comprise waxy pale green to brown, massive to coarsely foliated serpentinite, locally with ghosts of igneous olivine and/or orthopyroxene. Talc, tremolite/actinolite (green amphibole), and magnetite are also present. Fish-scale serpentinite occurs locally. Gabbro and diabase occur in small bodies less than 0.5 square km in area and are less common. They generally are found near bodies of ultramafic rock. Diabase is commonly found in or near exposures of the Campbell Range basalt.

A combination of contact features and geometric relationships supports the interpretation that these bodies are intrusions into Yukon-Tanana Terrane, not thrust slices of ophiolitic upper mantle as has been previously interpreted (Tempelman-Kluit, 1979; Mortensen and Jilson, 1985; Mortensen, 1992; Erdmer et al., 1998). Contacts are commonly sharp and not associated with a greater degree of deformation than away from the contact (Fig. 14a). Near their contact with ultramafic rocks, carbonate rocks are calc-silicate hornfels or skarn (Fig. 14b): green, coarse-grained and contain porphyroblasts of tremolite-actinolite, garnet and locally diopside. Dark argillite of unit Mvcl is harder and more massive near the contacts with ultramafic rocks, resembling pelitic hornfels. Geometrically, outliers of meta-sedimentary or meta-volcanic rocks within ultramafic rocks are roof pendants, with bedding and foliation of a similar character and orientation with rocks outside the bodies. Locally, contacts can be mapped up to one side of an ultramafic body and continued out the other side with minimal deviation. There are no observations that would permit placing a crust-penetrating thrust fault along any of the contacts with ultramafic rocks, a requirement of the ophiolite interpretation.

The age(s) of the ultramafic intrusions in Frances Lake area are not directly constrained. Together with gabbro, diabase, and leucogabbro, ultramafic intrusions define a magmatic corridor along the length of the Campbell Range, crosscutting all units described in this report, including the late Pennsylvanian to Early Permian

Campbell Range basalt. A ca. 274 Ma U-Pb age date has been obtained from a leucogabbro in McEvoy Lake area (105G/9) along this trend (J.K. Mortensen and D.C. Murphy, unpublished data). Plagiogranite from serpentinite-matrix melange in northwestern Finlayson Lake area, on strike from the Campbell Range trend, has been dated at 274.3 ± 0.5 Ma (Mortensen, 1992b). An upper age limit for the ultramafic intrusions is provided by the mid-Permian age of the polymictic conglomerate, which contains clasts of serpentinized ultramafic rock (Mortensen et al., 1997, 1999).

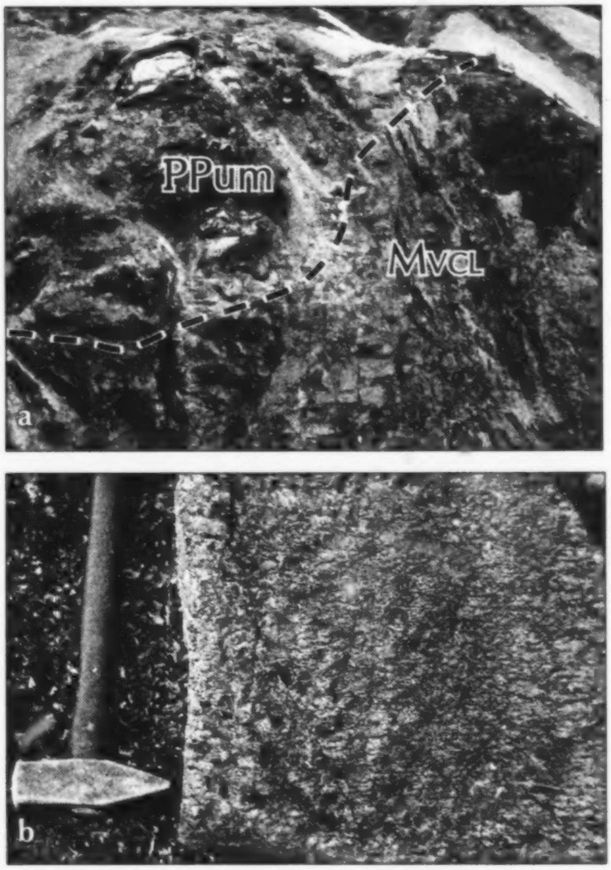


Figure 14. *Unit PPum: (a) sharp contact at base of ultramafic rocks, King Arctic jade mine; (b) skarn and marble near contact with ultramafic rocks of unit PPum.*

MINERAL OCCURRENCES AND POTENTIAL

Several types of mineral occurrences have been found in this part of Frances Lake area (Yukon MINFILE, 1997). Basalt-hosted volcanogenic massive sulphide (VMS) occurs in the Campbell Range basalt at the Money/Julia (#105H 074). Although just outside the area mapped, felsic volcanic-hosted massive sulphide is known at the Kneil (#105H 080) prospect. The King Arctic jade mine (#105H 014) is hosted in a large ultramafic body in Klatsa River area (105H/3) and Tuchitua property (#105H 016) is a former jade producer in an extensive ultramafic body straddling the Tuchitua River near its head. The Doug occurrence (#105H 015) is described as a Cu vein.

The fertile back-arc rocks of Yukon-Tanana Terrane that host the Finlayson Lake volcanic-hosted massive sulphide deposits are truncated by the Money Creek thrust in this area; however, VMS-style prospects occur in coeval volcanic arc rocks in the Money Creek thrust sheet, attesting to potential for new deposits in these rocks. In addition to the Kneil occurrence in Frances Lake area, barite and altered felsic meta-volcanic rocks with sulphides occur on the EXPO and TY claims of Cominco Ltd. and Atna Resources, respectively, and pyritic chlorite schist occurs on Expatriate Resources' SHUTOUT claims; all of these occur in Waters Creek map area (105G/1). Further indications of potential include numerous gossans in unit Mv in Frances Lake area, especially southeast of Jules Creek. These are underlain by altered and pyritic intermediate to felsic volcanic rocks with local base metal enrichments. A grab sample from one such gossan contained 373 ppm Cu, 3805 ppm Pb, 562 ppm Zn, 2.6 ppm Ag, 1980 ppm Mn, 109 ppm V and 14 ppb Au (A in Fig. 2, 466237E, 6783919N, NAD27, Zone 9; ICP-ES analysis by Acme Analytical Laboratories, Vancouver). Altered intermediate meta-igneous rocks also occur in unit Mch. These are weakly anomalous in base metals (B in Fig. 2, 58 ppm Cu, 8 ppm Pb, 110 ppm Zn, 31 ppm Ni, 41 ppm Co, 1213 ppm Mn, and 352 ppm V; 469888E, 6784385N, NAD27, Zone 9; analysis as above).

The new interpretation of mafic and ultramafic rocks in the area as intrusions opens up the possibility of magmatic Cu-Ni-PGM deposits. Sediments in local streams with ultramafic bodies in their catchment areas are highly anomalous (greater than 99.5 percentile for Yukon RGS dataset, Hornbrook and Friske, 1988) in Cu and Ni (Fig. 2). No sulphide concentrations were observed in the course of mapping.

LATE PALEOZOIC GEOLOGICAL HISTORY

As indicated by the rocks and relationships described in this report, Yukon-Tanana Terrane was an exciting place to be during the Late Paleozoic. The geological record during this time included:

1. Mississippian arc and back-arc magmatism and high-pressure metamorphism;
2. Early Pennsylvanian bioclastic carbonate sedimentation;
3. Pennsylvanian tectonism, sedimentation and magmatism including:
    a. thrusting along the Money Creek thrust (and possibly other structures to the south and west);
    b. deposition of flysch-like sediments and chert as an overlap onto the shortened terrane;
    c. ongoing deformation of the terrane, including the overlap sequence; uplift, erosion and sedimentation of the conglomerate in the footwall of the Jules Creek thrust;
    d. extrusion of basalt of unit PPC?b;
    e. thrusting on the Jules Creek thrust;
4. Late Pennsylvanian to Early Permian extrusion of the Campbell Range basalt as an overlap on the previously deformed terrane; coeval and younger intrusion of mafic and ultramafic rocks;
5. An Early Permian history recorded by the mid-Permian conglomerate which includes (Mortensen et al., 1997, 1999; J.K. Mortensen, pers. comm., 2000):
    a. high-pressure metamorphism of part of the terrane (clasts have same range of ages as *in situ* eclogite and blueschist at Faro, Ross River and in the St. Cyr Klippe);
    b. arc volcanism (clasts have similar ages to Permian Klondike Schist);
    c. uplift, erosion and deposition of the mid-Permian conglomerate.

CONCLUSIONS

1. The rocks and relationships described above attest to a previously undocumented period of intra-terrane deformation that occurred predominantly in the Pennsylvanian. This was between the periods of Mississippian and Permian events of arc- and back-arc magmatism and local high-pressure metamorphism that had been previously documented in Yukon-Tanana Terrane.
2. Although the contact relationships are unclear, coarse-grained high-pressure metamorphic rocks with early Mississippian cooling ages are clearly embedded within rocks of Yukon-Tanana Terrane. In southwestern Frances Lake area, they occur neither along the boundary with ancestral North America nor as part of Slide Mountain Terrane as previously inferred (Erdmer et al., 1998).
3. Numerous gossanous areas and known mineral showings attest to the potential for volcanic-associated mineral deposits in unit Mv.
4. The re-interpretation of ultramafic rocks as *in situ* intrusions rather than thrust slices opens up the possibility for magmatic Ni-Cu-PGM deposits in this area.

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Distribution of Miles Canyon basalt in the Whitehorse area and implications for groundwater resources

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Pearson, F.K., Hart, C.J.R. and Power, M., 2001. Distribution of Miles Canyon basalt in the Whitehorse area and implications for groundwater resources. *In:* Yukon Exploration and Geology 2000, D.S. Emond and L.H. Weston (eds.), Exploration and Geological Services Division, Yukon, Indian and Northern Affairs Canada, p. 235-245.

ABSTRACT

Miocene Miles Canyon basalts play a critical role in the historical development and modern economics of the City of Whitehorse. Where cut by the Yukon River, the unnavigable waters at Miles Canyon and the Whitehorse Rapids formed a natural terminus that became a transportation hub that in turn encouraged settlement. Today, this basalt is responsible not only for efficient and economical hydroelectric power, but also for hosting the groundwater resources for many of Whitehorse's rural residents. Much of the city is underlain by Cretaceous granodiorite of the Whitehorse Batholith, which is a relatively poor aquifer due to its lack of porosity. Miles Canyon basalt however, has significantly higher innate hydraulic permeability and thus provides better opportunities for additional groundwater resources and aquifer development. Miles Canyon basalts have reported hydraulic conductivity values around 2×10^{-6} m/s, which are 20 to 50 times higher than reported hydraulic conductivity values for unfractured granodiorite aquifers. As such, the loci of basalt limits have important implications for the siting of productive private water wells.

This paper summarizes details of Miles Canyon basalt occurrences within the limits of the City of Whitehorse and provides updated mapping of the extent and distribution of the basalt within the City. The discussion includes a summary of six outcrop observations, twelve water-well record data, a shallow reflected seismic survey and interpretation of regional aeromagnetic data related to basalt distribution. Thickness of Miles Canyon basalt intersected in drill holes ranges from as little as 1.8 m up to 110 m, although most drill holes did not penetrate the total basalt thickness.

RÉSUMÉ

Le basalte de Miles Canyon, d'âge Pliocène-Pléistocène, joue un rôle stratégique dans l'évolution historique et l'économie moderne de la ville de Whitehorse. Ce basalte est non seulement à l'origine d'une source d'hydroélectricité efficace et bon marché, mais assure également des ressources en eau souterraine pour nombre de résidents ruraux de Whitehorse. La ville repose en grande partie sur le granodiorite du batholithe de Whitehorse, d'âge Crétacé, un aquifère relativement pauvre à cause de sa faible porosité. Le basalte de Miles Canyon a enregistré des valeurs de conductivité hydraulique d'environ 2×10^{-6} m/s, ce qui est de 20 à 50 fois plus élevé que les valeurs observées dans des aquifères de granodiorite non fissurés. Ainsi, la localisation exacte des limites de distribution du basalte est un facteur important pour le choix de l'emplacement des puits artésiens.

Dans cet article, nous présentons un compte rendu des observations de basalte de Miles Canyon à l'intérieur des limites de la ville de Whitehorse, et révisons l'étendue et la distribution du basalte sous la ville. Nous analysons un résumé des observations de six affleurements, les fiches de douze puits artésiens, un levé de sismique-réflexion à faible profondeur, et interprétons les données d'un levé aéromagnétique régional sur la distribution du basalte. Les trous de forage qui pénètrent le basalte de Miles Canyon ont recoupé une épaisseur de basalte allant d'à peine 1,8 m jusqu'à 110 m, bien que la plupart des forages n'ont pas traversé l'épaisseur totale du basalte.

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INTRODUCTION

Miles Canyon basalts were critical to the origin and historical development of the City of Whitehorse. Cataracts formed by these flows formed a transportation terminus that required travelers, the railhead, and head of shipping to pay homage to the treacherous rapids and canyon. This encouraged settlement, commerce and prospecting. In 1958 the Whitehorse Rapids were tamed by a hydroelectric dam and, with a current installed capacity of 40 MW, have since supplied southern Yukon with clean and reliable electricity. In recent years, widespread rural residential developments within the city limits have come to rely on groundwater for household domestic water supplies. In areas where unconsolidated aquifers are not available, aquifers formed in Miles Canyon basalt are increasingly recognized as yielding a sufficient groundwater supply. With consistent demands for rural residential development and increasing pressure on aquifers, information regarding host rocks is increasingly in demand.

Much of the southern City of Whitehorse is underlain by the Cretaceous granodiorite of the Whitehorse Batholith (Hart and Radloff, 1990; Hart, 1995; Morrison, 1979), which is typically a poor aquifer due to its low permeability. In order to develop water wells with sufficient water supply in this type of host-rock, drillers and homeowners must intersect a water-producing fracture zone, or risk having to drill to excessive depths in order to encounter one. In at least one known example in the Wolf Creek subdivision, a well that had been drilled 50 m into granodiorite bedrock yielded negligible water supplies. With the current cost of drilling (a cased hole approximating $130/m), it is in the homeowner's best interest to know that sufficient water supplies are likely available at a reasonable drilling depth and cost at a specific site. Miles Canyon basalt is a lithology that presents less risk in drilling water wells, as aquifers hosted in these rocks typically yield adequate volumes sufficient for domestic use, and may locally be developed for more demanding users. Understanding the extent of Miles Canyon basalt therefore offers developers, drillers and homeowners more information in order to decide whether developing an on-site water supply is cost effective with respect to trucked water delivery.

GEOLOGY OF THE WHITEHORSE AREA

WHITEHORSE BATHOLITH

The Whitehorse Batholith extends over 600 km^2 including much of the area in and around Whitehorse (Fig. 1). It consists of a variably zoned Cretaceous intrusive body ranging from diorite to granite, but dominated by granodiorite that intrudes folded sedimentary and volcanic rocks of the Triassic Whitehorse Trough (Hart and Radloff, 1990). Although variably jointed, the granodiorite lacks a continuous, systematic joint set in three planes. The rocks are brittle and variably fractured a most fractures are steeply inclined or nearly vertical. Although fracture analysis has not been undertaken, regional structures typically trend northwesterly, with a more closely spaced series of smaller east-northeasterly trending faults and fractures (Hart and Radloff, 1990).

MILES CANYON BASALT

Miles Canyon basalt is the youngest bedrock lithology in the Whitehorse area (Wheeler, 1961; Hart and Radloff, 1990). It forms numerous disparate occurrences, the largest being a continuous sequence of flows between the McRae, Miles Canyon and Whitehorse Rapids localities. Most other occurrences are erosional remnants of previously larger exposures, up to a few square kilometres in area. Isotopic dating indicates that the larger sequence of flows exposed below the dam and at McRae are ~8.5 ± 1 Ma (Hart and Villeneuve, 1999). Except for the Wolf Creek occurrence, dated at 7.4 ± 1 Ma, the other occurrences have not been dated, but are likely Late Miocene. Locally, the basalts contain peat or bedded silt between the flows. The basalts are dominated by columnar-jointed, variably vesicular and amygdaloidal flows and scoria. Individual flows are up to 20 m thick, but are thinner, down to 1 m, below the hydro dam. Most exposures unconformably overlie weathered and oxidized granodioritic bedrock of the Whitehorse Batholith. However, some basalts overlie variably consolidated gravel of probable Neogene age. These conglomerates have been intersected in drilling. The basalts include dominantly aphyric, but locally diabasic, plagioclase-, augite-, olivine- and magnetite-bearing, weakly alkalic basalts, basanite, hawaiite and pantellerite (Eiché, 1985).

Miles Canyon basalt deposition post-dates most structural features such as faults, but the basalts have extremely well developed columnar joints that give rise to good vertical secondary permeability, and the connectivity of these joints also provides considerable horizontal permeability.

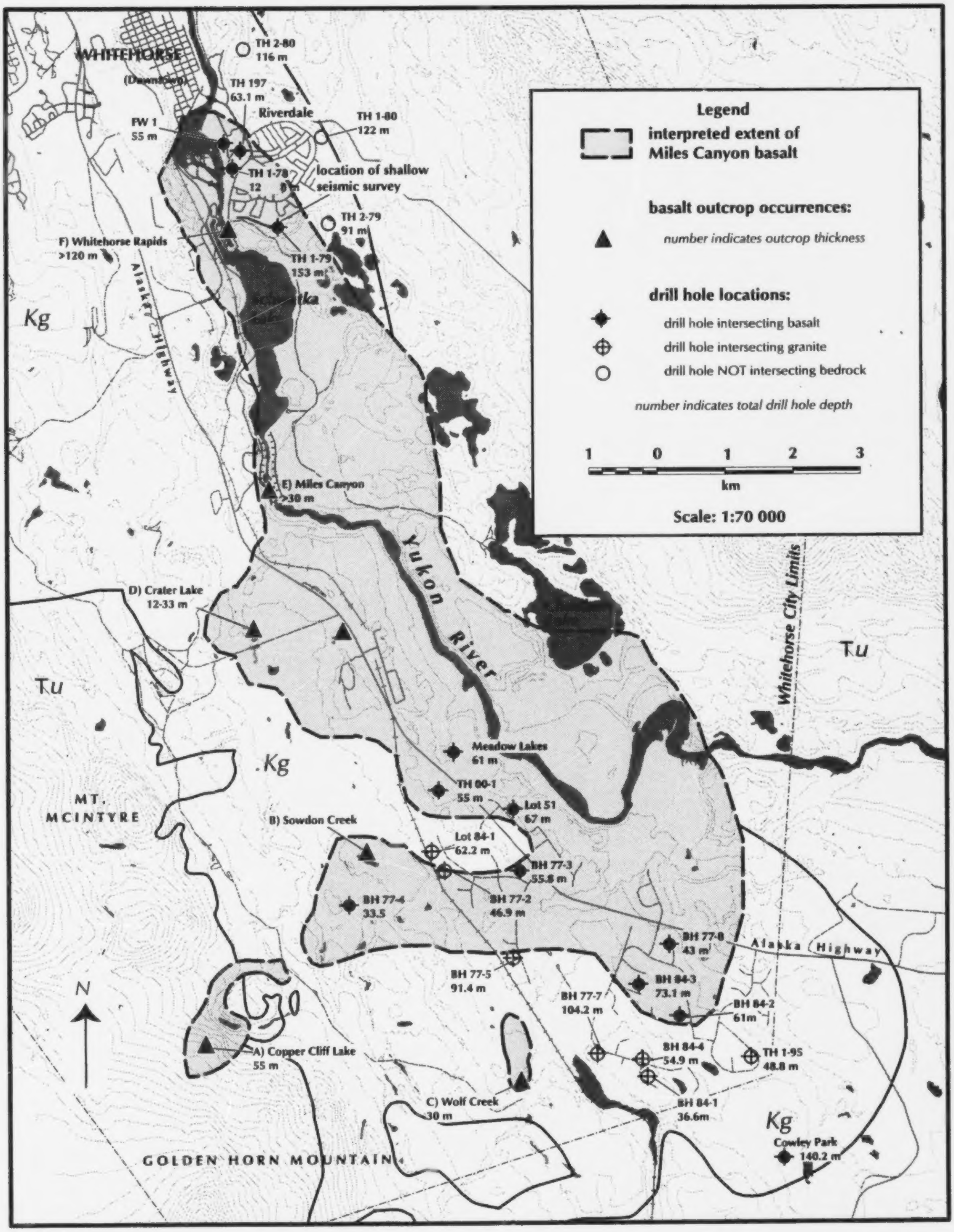
WHITEHORSE
(Downtown)
TH 2-80
116 m
TH 197
63.1 m
Riverdale
TH 1-80
122 m
FW 1
55 m
TH 1-78
12
location of shallow seismic survey
TH 2-79
91 m
F) Whitehorse Rapids
>120 m
TH 1-79
153 m
Alaska Highway
Kg
E) Miles Canyon
>30 m
Yukon River
D) Crater Lake
12-33 m
Ŧu
Whitehorse City Limits
Ŧu
Kg
MT. MCINTYRE
Meadow Lakes
61 m
TH 00-1
55 m
Lot 51
67 m
B) Sowdon Creek
Lot 84-1
62.2 m
BH 77-3
55.8 m
BH 77-4
33.5
BH 77-2
46.9 m
BH 77-8
43 m
Alaska Highway
BH 77-5
91.4 m
BH 84-3
73.1 m
BH 77-7
104.2 m
BH 84-2
61m
N
A) Copper Cliff Lake
55 m
BH 84-4
54.9 m
TH 1-95
48.8 m
C) Wolf Creek
30 m
BH 84-1
36.6m
Kg
Cowley Park
140.2 m
GOLDEN HORN MOUNTAIN
Legend
interpreted extent of Miles Canyon basalt
basalt outcrop occurrences:
number indicates outcrop thickness
drill hole locations:
drill hole intersecting basalt
drill hole intersecting granite
drill hole NOT intersecting bedrock
number indicates total drill hole depth
1 0 1 2 3
km
Scale: 1:70 000

Figure 1. Interpreted extent of Miles Canyon basalt in the Whitehorse area, with localities of drill holes and outcrops indicated in the Tables. Distribution of basalt was identified through compilation of outcrop localities, reported basalt intersections in drill hole data, interpretation of regional aeromagnetic data, and a reflected seismic survey. Kg = Cretaceous granite; Ŧu = Triassic Whitehorse Trough sedimentary rocks.

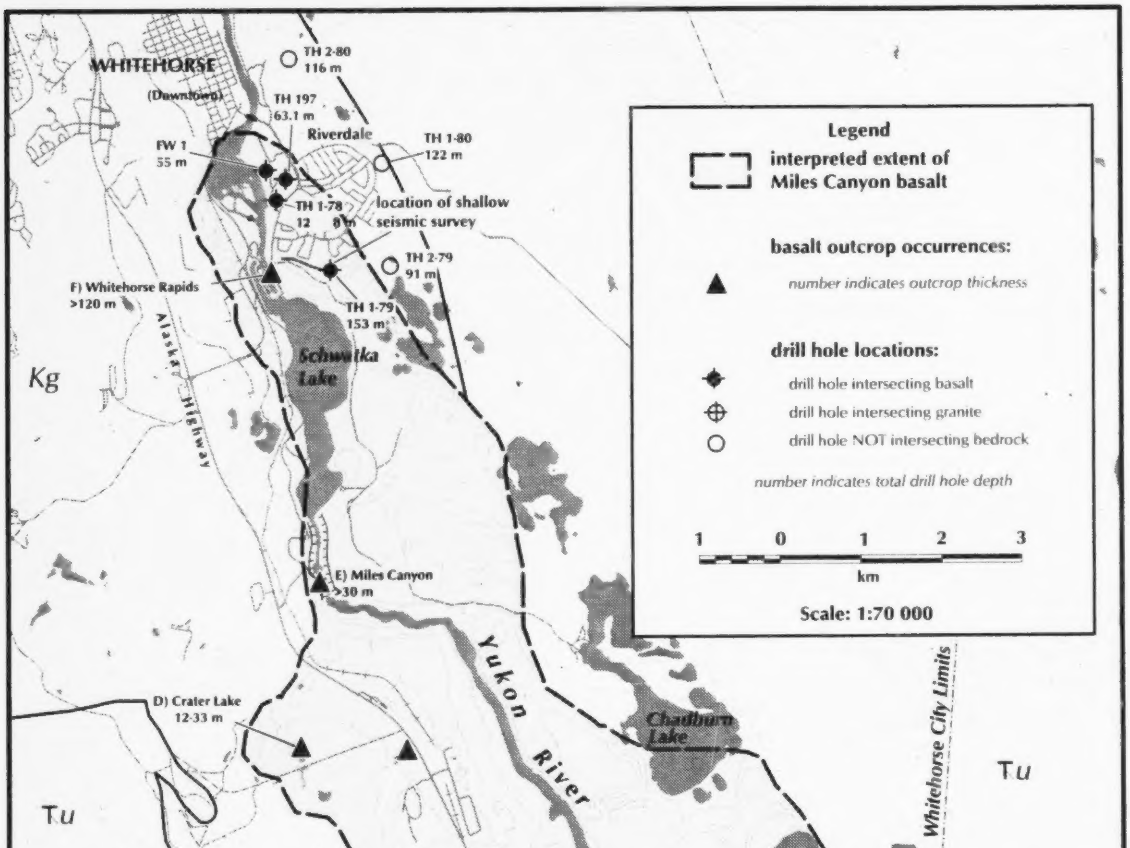
WHITEHORSE
(Downtown)
TH 2-80
116 m
TH 197
63.1 m
Riverdale
TH 1-80
122 m
FW 1
55 m
TH 1-78
12 8 m
location of shallow
seismic survey
TH 2-79
91 m
F) Whitehorse Rapids
>120 m
TH 1-79
153 m
Alaska Highway
Schwatka
Lake
Kg
E) Miles Canyon
>30 m
Yukon River
Chadburn
Lake
D) Crater Lake
12-33 m
Tu
Whitehorse City Limits
Tu
Meadow Lakes
61 m
Kg
TH 00-1
55 m
Lot 51
67 m
MT.
MCINTYRE
B) Sowdon Creek
Lot 84-1
62.2 m
BH 77-3
55.8 m
BH 77-4
33.5
BH 77-2
46.9 m
BH 77-8
43 m
Alaska Highway
N
BH 77-5
91.4 m
BH 84-3
73.1 m
BH 77-7
104.2 m
BH 84-2
61m
A) Copper Cliff Lake
55 m
BH 84-4
54.9 m
TH 1-95
48.8 m
C) Wolf Creek
30 m
BH 84-1
36.6m
Kg
Cowley Park
140.2 m
GOLDEN HORN MOUNTAIN
Legend
interpreted extent of
Miles Canyon basalt
basalt outcrop occurrences:
number indicates outcrop thickness
drill hole locations:
drill hole intersecting basalt
drill hole intersecting granite
drill hole NOT intersecting bedrock
number indicates total drill hole depth
1 0 1 2 3
km
Scale: 1:70 000

Figure 1. *Interpreted extent of Miles Canyon basalt in the Whitehorse area, with localities of drill holes and outcrops indicated in the Tables. Distribution of basalt was identified through compilation of outcrop localities, reported basalt intersections in drill hole data, interpretation of regional aeromagnetic data, and a reflected seismic survey. Kg = Cretaceous granite; Ŧu = Triassic Whitehorse Trough sedimentary rocks.*

Additionally, many flow surfaces are marked by highly vesicular flow-tops and -bottoms, or scoria, and an unconsolidated break or porous materials. These provide thick regions of continuous horizontal primary permeability.

SURFICIAL GEOLOGY

Whitehorse is largely within the Yukon River Valley, which is a broad, terraced landscape composed of low-relief glaciolacustrine, fluvial and aeolian material dissected by the Yukon River. Elevations of the valley floor ranges between 660 m and 690 m above sea level (ASL). The landforms of the Whitehorse area are attributable to the last glacial retreat that likely occurred between 35,000 and 12,000 years ago. The area has a complex terrain of glacial, glaciofluvial and glaciolacustrine deposits that are typical of deglaciation in mountainous regions (Mougeot GeoAnalysis and Agriculture and Agri-Food Canada, 1997). These deglaciation features substantially affect and control the surface and groundwater resources in unconsolidated materials.

Thick sequences of glaciofluvial sand and gravel deposited in the centre of the Whitehorse valley form a dramatic knob and kettle topography seen in the Chadburn and Long lakes areas. This material hosts the very productive Selkirk aquifer that is the source of the City's municipal groundwater supplies (Gartner Lee Limited, 1998). At elevations above 730 m ASL, morainal material dominates the unconsolidated deposits. This material typically lacks sufficient permeability to be exploited for domestic water supplies. This necessitates that many developers of domestic water wells in rural residential areas (e.g., Wolf Creek, Cowley Creek) utilize bedrock aquifers.

Table 1. *Significant outcrop occurrences of Miles Canyon basalt in Whitehorse area,*

Site ID	Location	Description	Thickness	Reference	Underlying material
A	Copper Cliff Lake, Golden Horn Mountain	Massive flows and oxidized scoria. Topographically highest, and most southerly locality. Associated 1-3 m thick, east-northeast-trending dykes.	55 m	Hart and Villeneuve, 1999	
B	Sowdon Cr.–between Copper Haul Rd. and Wolf Creek Subdivision	A plateau of basalt with abundant outcrops and exposure along glacial meltwater channels.	Unknown		Probably granodiorite
C	Wolf Creek/ Keewenaw	Small exposure of columnar-jointed basalt flow on northwest side of Wolf Creek. Paleomagnetically reversed. 7.1 ± 0.4 Ma K-Ar date.	30 m	Hart and Villeneuve, 1999	Oxidized and altered Whitehorse Batholith granodiorite exposed in stream-cut under flows.
D	Mt. Sima Road/ Crater Lake/McRae	Large plateau of basalt exposed along Crater Lake and near McRae and in shallow boreholes in area. Paleomagnetically normal. 8.8 ± 0.6 Ma K-Ar date.	12 to 33 m	Piteau Engineering Ltd., 1991; Hart and Villeneuve, 1999	"Beneath the basalt layer, a 1.5-m-thick clay rich layer was encountered and below it a...zone of weathered feldspathic rock." Northerly exposures overlie strongly oxidized and deeply weathered Whitehorse Batholith granodiorite (gruss).
E	Miles Canyon	Type location – outcrop also found 1 km upstream near Canyon City and 1 km downstream near Schwatka Lake boat ramp. Paleomagnetically normal.	>30 m		Oxidized and altered Whitehorse Batholith granodiorite.
F	Whitehorse Rapids	Site of hydroelectric project, abundant outcrop along river. Paleomagnetically normal. Several Ar-Ar and K-Ar dates indicate age of 8.5 Ma.	>120 m	Hart and Villeneuve, 1999	Variably lithified gravel.

NATURE AND DISTRIBUTION OF MILES CANYON BASALT

Attributes of six significant Miles Canyon basalt outcrops are summarized in Table 1. This table presents the thickness of the basalt package at that site (if known) and the reported underlying material. Outcrop locations documented in the table are illustrated with triangular symbols on Figure 1. Subsurface exposures of Miles Canyon basalt are also known from water-well drilling of bore holes and mineral exploration diamond drilling.

Table 2. *Occurrence of Miles Canyon basalt in Whitehorse area.*

Site ID	Location	Description	Thickness	Reference	Underlying material
TH 1-97	near Selkirk Elementary School	Well drilled as part of 1997 warm water exploration program. Basalt intersected 52.1 m below surface (585.5 m ASL), total hole depth = 63.1 m	>11 m	Gartner Lee Limited, 1999	unknown
FW1	original fish hatchery well, Selkirk Well Field	Well abandoned. Basalt intersected 52 m below surface (585 m ASL), total hole depth = 55 m	>3 m	Drillhole log, Interior Water Wells Ltd., 1985	unknown
TH 1-78	near Nisutlin Dr. & Selkirk St.	1st deep test-well in Selkirk Well Field. Basalt intersected 67 m below surface (570.48 m ASL), total hole depth = 128.3 m	37.8 m	Stanley Associates, 1978	"- Sand & gravel, cemented (mainly granodiorite) - gravel, with greenish silt lenses - gravel, large number of rounded chert pebbles"
TH 1-79	near Chadburn Lake Rd., south of Firth Rd.	Deep test-well drilled in 1979. Basalt intersected 42.5 m below surface (609.5 m ASL), total hole depth = 153 m	110 m	Stanley Associates, 1980	"sand"
MLGC	Meadow Lakes Golf Course	Clubhouse well. Relatively productive (1 L/s). Basalt reported 50 m below surface (668 m ASL), total hole depth = 60.9 m	>11 m	Drillhole log, Lundgren Well Drilling Ltd., 1999	unknown
TH 00-1	test-well, Wolf Creek North	Thin layer of basalt intersected 37 m below surface (689 m ASL) overlying deeply weathered granite. Basalt sill or dyke encountered after 11 m of granite.	1.8 m	Gartner Lee Limited, 2001	11 m of weathered granodiorite (gruss), 4 m of basalt intersected below.
Lot 51	28 Harvey Rd., Pineridge subdivision	Residential well. Basalt reported 43 m below surface (684 m ASL), total hole depth = 66.7 m	>24 m	Drillhole log, Fredelena Enterprises Ltd., 1999	unknown
77-3	5 Harbottle Rd., Wolf Creek subdivision	Test-well drilled in 1977. Basalt reported 36 m below surface (700 m ASL), total hole depth = 55.8 m	>19	Golders Associate, 1977	unknown
77-4	west of Wolf Creek subdivision	Test-well drilled in 1977. Basalt reported 12 m below surface (775 m ASL), total hole depth = 33.5 m	>21	Golders Associate, 1977	unknown
84-3	Lot 78, Mary Lake subdivision	1984 test-well. Basalt reported 44.5 m below surface (694 m ASL), total hole depth = 73.1 m	> 29	Thompson Geotechnical, 1984	unknown
77-8	between Orchid Pl. & Alaska Hwy., Mary Lake subdivision	Test-well drilled in 1977. Basalt reported 40.2 m below surface (687 m ASL), total hole depth = 43.3 m	> 3	Golders Associates, 1977.	unknown
	Cowley Park	Mineral exploration diamond drilling intersected basalt at a depth of 49 m	22	Bidwell, 1987	gravel

Additional localities, or the extent of known localities, are interpreted from aeromagnetic and seismic data.

DRILL HOLES

Attributes of 12 drill holes reporting intersecting Miles Canyon basalt are presented in Table 2. Similarly, this table summarizes the reported depth to basalt, basalt thickness and underlying material (if known). Drill holes are symbolized on Figure 1 with a solid, crossed circle and labeled with the total drill hole depth. Figure 1 also identifies drill holes intersecting granodiorite (shown as an open, crossed circle) and deep drill holes not intersecting bedrock (shown as a small open circle). Wells developed in granite are typically located at the southern end of the city. Deep overburden drill holes consist of a series of three deep holes drilled by Stanley Associates Engineering Ltd. (1979, 1980) in the Riverdale area.

Drill hole data has been compiled from hydrogeological studies conducted during subdivision developments, the city's hydrogeological exploration in the late seventies, and private water-well records (Gartner Lee Limited, 2000a). Regretfully, there is no archive of well-site information available to the public.

AEROMAGNETIC INTERPRETATION

The magnetic susceptibility of Miles Canyon basalt is several times greater than most of the Whitehorse Batholith. The only other rock-type with a high magnetic signature is the magnetite-rich skarn of the Whitehorse Copper Belt. As such, interpretation of regions of elevated magnetic response from existing aeromagnetic data can aid in locating sub-surface occurrences, or the limits of surface exposures. Unlike the skarn, Miles Canyon basalt likely yields relatively flat profiles contrary to the spiky profiles across skarn occurrences (Tenney, 1981). However, it should be noted that preliminary information indicates that at least some of the basalts are reversely magnetized, thus yielding negative anomalies.

Regional aeromagnetic data (Lowe et al., 1999) has been used to help identify the buried extent of Miles Canyon basalt; several local aeromagnetic highs in the southern Whitehorse area conform with drill hole intersections of the basalt. For example, there are two regions with anomalously high values in the Wolf Creek and Mary Lake subdivision areas. The Wolf Creek high coincides with basalt intersected in drill hole BH 77-3, while the Mary Lake high coincides with basalt intersected in drill holes BH 77-8, BH 84-2 and BH 84-3. A large aeromagnetic anomaly east of Schwatka Lake is interpreted to represent the buried extent of basalt between Miles Canyon and the Whitehorse Rapids. It should be noted that these data are coarse, and refinements could be made with better data.

SEISMIC SURVEY

A 575-m-long seismic survey was completed by the authors along the 138kV transmission line running east of the Whitehorse Rapids and the Riverdale subdivision (behind Boswell Crescent and sub-parallel to the Chadburn Lake road) in November 1998. The survey was undertaken as a test to find:

1) depth to bedrock,

2) attitude of contact, and

3) the eastern edge of the basalt flow.

The data was acquired with a 48-channel Geometrics Strataview S-48, using 12-gauge shotgun slugs shot into frozen ground as the energy source. The survey was conducted using an inline array with a phone-spacing of 2 m and a shot-spacing of 4 m to yield 24-fold coverage. Shot records were 512 milliseconds long and recorded using a 500 Hz high-cut analog pre-acquisition filter. Post-acquisition processing consisted of bandpass filtering (30-150 Hz), surgical muting of the blast wave and ground roll, normal moveout analysis and application, CDP sort and stack, frequency filtering and trace balancing prior to final plotting.

The data are interpreted to show a weak but continuous reflector (A) that dips to the east on the section (Fig. 2). Above this reflection, there are a series of sub-parallel, west-dipping reflections (B) that appear to truncate against reflector (A). In the lower portions of the section, there are continuous flat reflections (C). A continuous reflection (A') is below and parallel to (A), and there are several poorly developed reflections (D) between (A) and (A'). Strongly curved arrivals have been ignored as they likely represent remnant reflections or multiples. The continuity of the reflection (A) across the section and its discordance with the reflections (B) and (C) suggest that this likely represents the upper surface of the basalt flow. Reflection (A') is likely a multiple reflector with no relevance. Depth to top of flow is highly dependent upon the velocity model chosen. A model assuming unsaturated, unconsolidated sediments yields a depth to surface (A) at approximately 30 m to 190 m across the section. This depth is generally supported by a drill hole

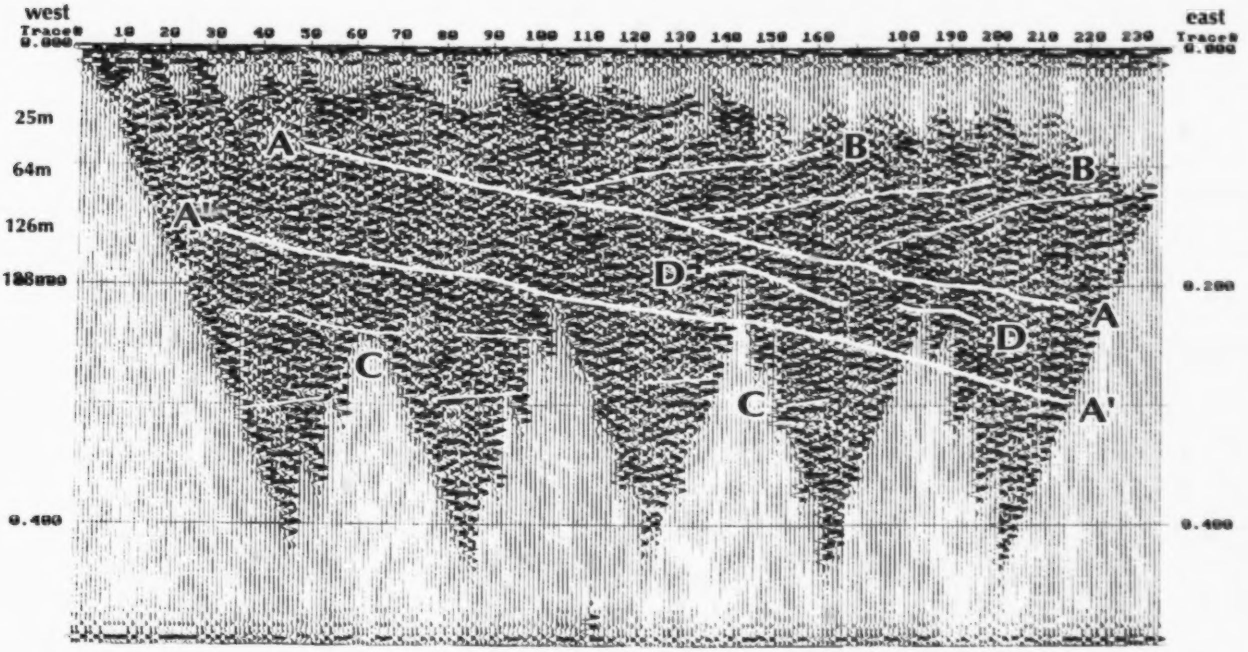

Figure 2. *Seismic profile generated from survey undertaken along the high-voltage transmission line south of Riverdale with highlighted reflectors. Vertical scale of two-way travel-time in milliseconds. Metre-scale approximate as it is model dependent. Numbers on horizontal scale are geophone sites. Total horizontal section is approximately 560 m. Interpretations of results are in the text.*

intersection (TH 1-79, 40 m off-section) with the upper basalt surface at a depth of 42 m (Fig. 1). If reflection (A') is the base of the flow, the thickness of the unit is about 80-100 m, however if reflectors (D) are the bottom of the flow, the flows are considerably thinner.

DISCUSSION

From the information presented above, a few general observations should be made:

1. The extent and thickness of Miles Canyon basalt varies widely throughout the study area. The distribution shown on Figure 1 is likely much less extensive than when the basalt was originally deposited. Significant erosion by at least four glaciations and incision by the Yukon River substantially reduced the extent of the unit. Glacial erosion has also reduced thickness of the basalt substantially. For example, in well TH 00-1, drilled north of Wolf Creek, only 1.8 m of basalt flows were intersected, and erosional down-cutting is suspected. Local paleo-topographic highs of underlying granodiorite bedrock locally protrude through the basalt such as seen in Miles Canyon or in the Wolf Creek subdivision area.
2. The eastern extent of the Miles Canyon basalt in the Chadburn Lakes/Riverdale area is defined by the absence of lithified materials. Drill hole TH 2-79 south of Riverdale was drilled to a depth of 91 m without encountering any bedrock. Hole TH 1-79, less than 900 m further west, intersected Miles Canyon basalt 42 m below the surface. The seismic survey was conducted to follow up on this observation and investigate the eastern extent of the basalt. As stated earlier, an east-dipping reflector was observed and is interpreted to be the upper basalt surface. This surface shallowly dips eastward, which the authors currently interpret to represent an erosional surface.

3. In at least two water wells, basalt dykes or sills have been intersected within granodiorite host rocks (Gartner Lee Limited, 2001; R. Zuran, pers. comm., 2000). These basalt occurrences have been successfully developed for groundwater supplies, although it is not certain whether the permeability results from joints in the basalt, or fractures in the structure that host the basalt. Owing to the relative sparseness of bedrock information in water-well records, these two intersections of basalt dykes or sills suggest that these features may be more common in the Whitehorse Batholith than originally recognized.

IMPLICATIONS FOR GROUNDWATER RESOURCES

Bedrock lithology potentially has significant economic impact on domestic water-well development costs. In many rural areas of the City of Whitehorse, unconsolidated glacial deposits do not yield suitable aquifers for domestic water usage, and therefore bedrock aquifers are developed. These unconsolidated deposits may either be unsaturated or of insufficient permeability to yield adequate water supplies. In the Wolf Creek and Pineridge rural subdivision areas, 85% of homes use domestic wells for water supplies. Approximately half of those well records which reported stratigraphy, developed wells in bedrock aquifers (Gartner Lee Limited, 2000b).

A summary of documented bedrock aquifer performance characteristics is presented in Table 3. These data are compiled from a variety of hydrogeological studies conducted in the Whitehorse area over the last 30 years. These studies reported pumping test data of wells and calculated transmissivity (T) values for the wells. Transmissivity is a measure of the ability of the aquifer to transmit water and is defined as the hydraulic conductivity (K) times the thickness of the aquifer. Hydraulic conductivity generally is the ease at which water can flow through the soil or rock. It is measured as the volume of water (m^3) that flows through a unit area (m^2) in a given period of time (seconds) and a unit change in head of water. It is expressed as m/s (Freeze and Cherry, 1979). Well data presented in Table 3 has been grouped into three broad categories reflecting the reported bedrock type hosting the site's water well.

Wells developed in granodiorite generally fall into two broad groupings–those with very low hydraulic conductivity (K) values and a couple of wells with relatively high K values. It is interpreted that the two wells with high hydraulic conductivity (wells BH 84-1 and TH 1-95) intersected fracture zones within the granodiorite and therefore were able to produce higher

Table 3. *Summary of bedrock aquifer performance parameters.*

Well	Reported Transmissivity (m2/s)	Interpreted Aquifer Thickness (m)	Hydraulic Conductivity (m/s)	Reference
Miles Canyon Basalt				
BH 77-3	4.6×10^{-5}	12	3.9×10^{-6}	Golders Associates, 1977
BH 77-4	3.5×10^{-5}	21	1.7×10^{-6}	Golders Associates, 1977
BH 77-8	1.5×10^{-5}	3	5.1×10^{-6}	Golders Associates, 1977
BH 84-3	1.0×10^{-5}	11	9.3×10^{-7}	Thompson Geotechnical, 1984
TH 1-00	5.3×10^{-6}	5	1.1×10^{-6}	Gartner Lee Limited, 2001
Unfractured Granodiorite				
BH 77-1	4.6×10^{-6}	30	1.5×10^{-7}	Golders Associates, 1977
BH 77-6	-	53	2.3×10^{-8}	Golders Associates, 1977
BH 77-7	8.1×10^{-6}	47	1.7×10^{-7}	Golders Associates, 1977
BH 84-1	9.3×10^{-7}	25	3.7×10^{-8}	Thompson Geotechnical, 1984
Fractured Granodiorite				
BH 84-1	9.1×10^{-4}	4	2.3×10^{-4}	Thompson Geotechnical, 1984
TH 1-95	2.5×10^{-5}	2 (screened interval)	1.7×10^{-5}	Hydrogeological Consultants, 1995

yields. These two wells had K values of 2.3×10^{-4} and 1.7×10^{-5} m/s. The majority of wells developed in granodiorite, which had very low K values, are interpreted to be representative of unfractured granodiorite bedrock. Wells in unfractured granodiorite report K values ranging from 1.7×10^{-7} to 2.3×10^{-8} m/s. This range of K values is similar to that reported for silt or glacial till (Freeze and Cherry, 1979).

In addition to the wells reported in Table 3, the authors are aware of one water well drilled in granodiorite and located in the Wolf Creek subdivision that failed to produce any significant water after drilling through almost 50 m of bedrock. This well was abandoned, and the unfortunate homeowner advanced a second well elsewhere on the property. From the second hole, they were able to develop adequate water supplies at a total depth of 23 m.

The data in Table 3 demonstrate that the Miles Canyon basalt has relatively consistent hydraulic conductivity (K) values ranging from 5.1×10^{-6} to 9.3×10^{-7} m/s with a median K value of 1.7×10^{-6} m/s. These values generally are within the published range for hydraulic conductivity of permeable basalt, which range from 1×10^{-2} m/s to 1×10^{-7} m/s (Freeze and Cherry 1979) and equivalent to silty sand aquifer.

Based on the data, two broad conclusions can be drawn:

- Miles Canyon basalt has relatively consistent aquifer performance parameters. Aquifers in the basalt are not highly productive, but with sufficient thickness are commonly adequate for single residence usage.
- Wells developed in granodiorite have much more variable aquifer performance. If a fracture zone is intersected in the granitic rock, adequate water supplies can be developed. If a fracture zone is not intersected in the drill hole, the well may yield inadequate water supplies, or may require excessive drilling depths.

CONCLUSION AND RECOMMENDATIONS

In conclusion, the Miles Canyon basalt aquifers offer rural homeowners that are considering developing a water well greater certainty of success despite its typical lower yields. Areas underlain by granodiorite represent a greater financial risk due to the uncertainty associated with need to intersect a suitable water-bearing fracture within the crystalline bedrock. With drilling costs as much as $130/m, knowledge of bedrock type can help homeowners weigh the costs and associated risks associated with developing a private water well.

Based on the observations presented in this paper, we recommend that:

- Due to the significance of bedrock type and related hydraulic conductivity on domestic water well yields, all future wells drilled into bedrock report the rock type (lithology) intersected as part of the drilling log.
- A publically available water-well registry be established in the Yukon to record well locations, geologic materials intersected, and groundwater conditions. A well registry is needed to document groundwater conditions, protect groundwater resources, and provide a valuable information source for all water users, regulatory agencies and geoscientists. Well registries have been maintained in all provinces of Canada for many years and are often supported by regulatory requirements.
- Further work is required to more thoroughly understand the distribution of Miles Canyon basalt occurrences. Additional localities can be discovered by outcrop mapping, low-level airborne aeromagnetic survey, ground magnetic follow-up and seismic surveys.

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Glass-fission-track ages of Late Cenozoic distal tephra beds in the Klondike district, Yukon Territory

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ABSTRACT

A distinctive and widespread tephra bed is a very useful stratigraphic tool, especially if its age is accurately and precisely known. However, distal tephra beds, like those in the Klondike region of the Yukon, are difficult to date because of their fine grain size and contaminated character. Grain-specific methods, such as the fission-track and ^{40}Ar/^{39}Ar techniques, are essential for reliable results.

Three rhyolitic tephra beds, each with a homogeneous glass composition, have been dated by the glass-fission-track method. Mosquito Gulch tephra is 1.42 ± 0.16 Ma and dates an intermediate-level terrace on Bonanza Creek. Quartz Creek tephra is 3.00 ± 0.33 Ma and confirms a late Pliocene age for the upper part of the White Channel gravel. Furthermore, the presence of the Quartz Creek tephra in an ice-wedge cast indicates that permafrost conditions must have existed in west-central Yukon at this time. The Jackson Hill tephra is 0.13 ± 0.03 Ma.

RÉSUMÉ

Une strate distincte et étendue de tephra est un outil stratigraphique très utile, en particulier si l'on connaît son âge exact et précis. Toutefois, les strates de tephra distales, comme celles de la région du Klondike au Yukon, sont difficiles à dater en raison de leur faible granulométrie et de leur contamination. Des méthodes propres au grain, comme la datation à partir des traces de fission et la technique ^{40}Ar/^{39}Ar, sont essentielles pour obtenir des résultats fiables.

Trois strates de tephra rhyolitique, chacune ayant une composition vitreuse homogène, ont été datées à partir des traces de fission du verre. Le tephra du ravin Mosquito date de 1,42 ± 0,16 million d'années et a permis de déterminer l'âge d'une terrasse de niveau intermédiaire sur le cours d'eau Bonanza. Le tephra du cours d'eau Quartz est vieux de 3,00 ± 0,33 millions d'années et confirme que la partie supérieure du gravier de White Channel remonte au Pliocène supérieur. En outre, la présence de tephra du cours d'eau Quartz dans une fente de glace fossile indique qu'il a dû y avoir du pergélisol dans le centre-ouest du Yukon à cette époque. Le tephra de Jackson Hill date de 0,13 ± 0,03 million d'années.

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INTRODUCTION

The Klondike region (Fig. 1) is located within the influence of volcanoes in the Wrangell Mountains and the more distant Alaska Peninsula-Aleutian arc. As a result, the late Cenozoic sediment of the Klondike region contains a large number of distal tephra beds. This situation holds promise for the eventual development of a comprehensive tephrochronological record, which, in turn, will facilitate the assembly of a reliable, regional, time-stratigraphic framework for the late Cenozoic deposits of the Klondike region. This type of time record would help to improve strategies for gold exploration, as well as greatly support other geoscience projects, especially those studies aimed at elucidation of the nature and timing of late Cenozoic environmental change.

With this objective in mind, tephra studies in the Klondike district began in earnest a few years ago. The authors' findings, based on tephra samples collected by them and received from others prior to 1996, have recently been detailed (Westgate et al., 2000; Preece et al., 2000). During the last two years, the authors have collected and received – especially from A. Duk-Rodkin, Geological Survey of Canada, Calgary – many tephra samples, all of which have been carefully documented as to location and stratigraphic setting. Many of these samples have already been characterized, but a large number await study.

The value of a tephra bed as a stratigraphic tool is considerably enhanced if its age is accurately and precisely known. However, the age of distal tephra beds is not easily determined because of their fine grain size and contaminated character. The application of grain-specific geochronological methods is essential for reliable results. We have developed two fission-track (ft) dating methods suited to distal tephra beds, both of which involve the use of the hydrated glass shards (Westgate et al., 1997). The isothermal plateau fission-track (ITPFT) method requires a thermal pretreatment to correct for partial fading of fission tracks and can be applied to tephra beds whose glass shards are larger than 125 µm (Westgate, 1989; Sandhu et al., 1993). The second method uses the mean diameter of the spontaneous and induced fission tracks to correct for this track-fading effect and can be used for tephra beds whose glass shards are as small as 60 µm (Sandhu and Westgate, 1995).

Distal tephra beds in the Klondike region that are derived from volcanoes in the Alaska Peninsula-Aleutian arc (type I tephra beds in the terminology of Preece et al., 1999), all contain abundant bubble-wall glass shards and are readily dated by glass-ft methods. Tephra beds related to volcanoes in the Wrangell Mountains (type II beds) are very pumiceous and not well suited to dating by glass-ft methods. However, some type II beds contain very small amounts of bubble-wall and chunky glass which allow their

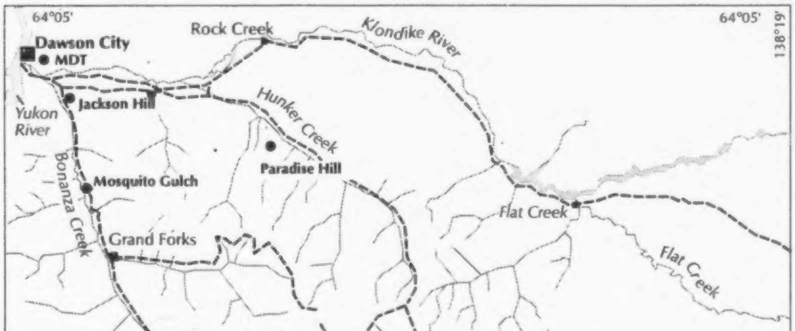
64°05'
64°05'
138°19'
Dawson City
MDT
Rock Creek
Klondike River
Jackson Hill
Yukon River
Hunker Creek
Paradise Hill
Bonanza Creek
Mosquito Gulch
Flat Creek
Flat Creek
Grand Forks
Quartz Creek
Jensen Creek
Readford
Sulphur
Indian River
Sulphur Creek
Dominion Creek
Granville
Dominion
168°
132°
68°
68°
Alaska
Yukon
Map Area
WVF
AP-AA
54°
54°
168°
132°
139°30'
63°30'
138°19'
63°30'
Legend
● sample location
■ historic site
---- road
WVF Wrangell Volcanic Field
AP-AA Alaska Peninsula - Aleutian Arc
MDT Midnight Dome Terrace
0
5
10
15
km

Figure 1. *Location of tephra samples dated by the glass-fission-track method.*

age to be determined by these methods, but large samples must be processed in order to recover the required amount of glass.

This report presents the results of the application of the diameter-correction-fission-track (DCFT) dating method to three tephra beds in the Klondike region: Mosquito Gulch, Jackson Hill, and Quartz Creek tephra beds (Fig. 1).

LITHOSTRATIGRAPHIC AND GEOMORPHIC SETTING OF TEPHRA BEDS

Mosquito Gulch tephra (UT19) occurs as a 2-cm-thick, discontinuous bed within alluvium on an intermediate terrace of Bonanza Creek (Naeser et al., 1982; Preece et al., 2000). This terrace, called Archibald's Bench, is approximately 37-42 m above present-day river level, on the right bank, and is about 8 km upstream from the confluence with the Klondike River (Fig. 1). It was formed subsequent to deposition and extensive dissection of the White Channel gravel (Milner, 1976). Unfortunately, the exposure containing Mosquito Gulch tephra was destroyed a few years ago during placer mining operations. The tephra occurred in silty clay overbank deposits that covered 1 m of gravel, which, in turn, rested on a well developed strath terrace. The overbank sediment was about 1 m thick and was unconformably overlain by 10 m of gravel and sand. The age of Mosquito Gulch tephra dates formation of Archibald's Bench on which it sits and provides a minimum age for the Klondike gravel, deposited during the first major expansion of the Cordilleran Ice Sheet (Froese et al., 2000).

Jackson Hill tephra (UT1637) takes its name from Jackson Hill, located 5 km east of Dawson City (Fig. 1). Forty metres of White Channel gravel are covered by up to 50 m of Klondike gravel at this site (Figs. 2, 3). The tephra is present in the upper part of a 2-m-thick gully-fill deposit, the gully being incised about 10 m into the Klondike gravel, close to the level of the highest terrace along the

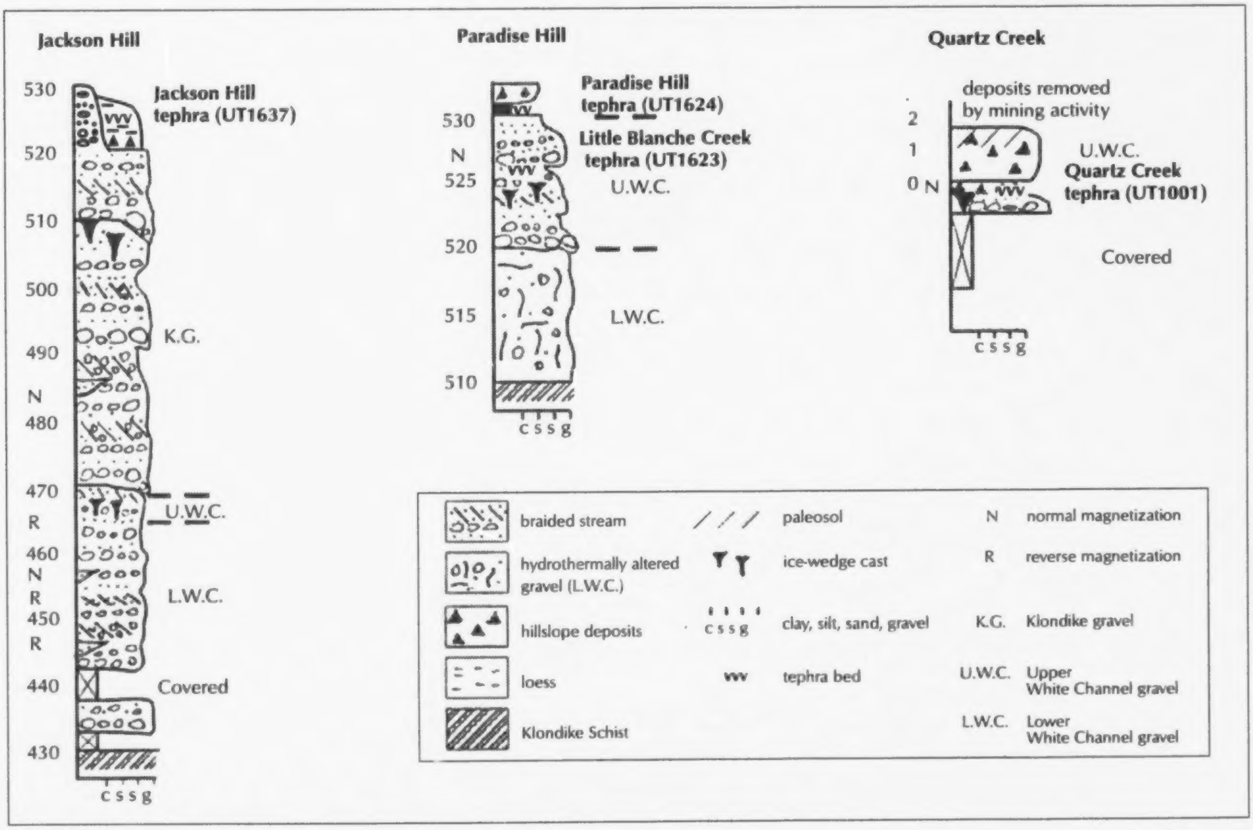
Jackson Hill
530
520
510
500
490
N
480
470
R
460
N
R
450
R
440
430
Jackson Hill tephra (UT1637)
K.G.
U.W.C.
L.W.C.
Covered
c s s g
Paradise Hill
530
N
525
520
515
510
Paradise Hill tephra (UT1624)
Little Blanche Creek tephra (UT1623)
U.W.C.
L.W.C.
c s s g
Quartz Creek
deposits removed by mining activity
2
1
0 N
U.W.C.
Quartz Creek tephra (UT1001)
Covered
c s s g
braided stream
hydrothermally altered gravel (L.W.C.)
hillslope deposits
loess
Klondike Schist
paleosol
ice-wedge cast
c s s g clay, silt, sand, gravel
tephra bed
N normal magnetization
R reverse magnetization
K.G. Klondike gravel
U.W.C. Upper White Channel gravel
L.W.C. Lower White Channel gravel

Figure 2. The lithostratigraphic setting of tephra beds at Jackson Hill, Paradise Hill and Quartz Creek sites. Elevation in metres is given for the first two localities, but only the thickness is given for the Quartz Creek site.

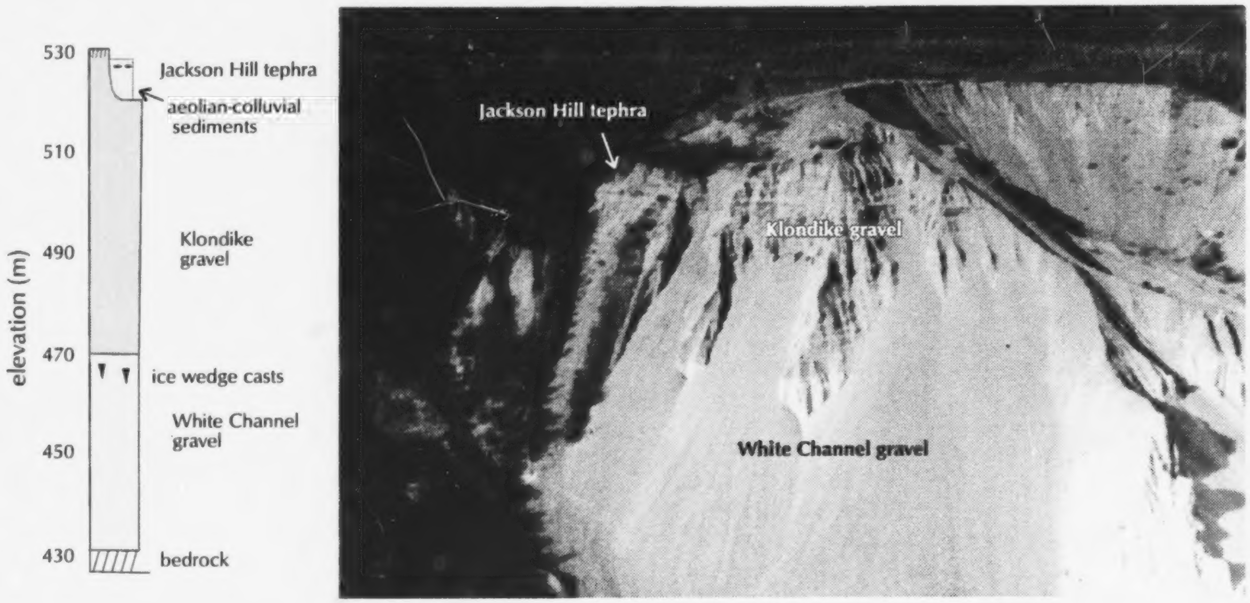

***Figure 3.** The geomorphic and stratigraphic setting of Jackson Hill tephra.*

Klondike River (Fig. 3). The gully-fill sediments consist of 0.5 m of matrix-supported gravel overlain by 1.5 m of massive to crudely stratified, organic-rich silt. Discontinuous pods of Jackson Hill tephra, up to 3 cm thick, occur 50 cm below the surface in this silt. The lower diamict is interpreted as a hillslope deposit derived from downslope movement of the Klondike gravel into the gully, while the overlying silt is thought to represent retransported loess. The age of this tephra bed will offer another minimum age for the Klondike gravel. Its fine grain size places it at the very limit of tephra that we can date by our glass-ft methods.

Quartz Creek tephra (UT1001) occurs in a colluviated facies of the Upper White Channel gravel (Froese et al., 2000) at a site located 35 km southeast of Dawson City near the confluence of the Little Blanche and Quartz creeks (Fig. 1). Mining activities have exposed 2 m of massive fluvial gravel that is separated by a bedrock high from the more extensive, and slightly lower, colluviated facies (Fig. 4). Locally, the tephra has been preserved in an ice-wedge cast (Fig. 4). Hence, its emplacement must have shortly preceded thawing of the ice wedge, a feature that can only form in the continuous permafrost zone. The age of Quartz Creek tephra would not only date the Upper White Channel gravel but give the timing of the onset of permafrost conditions in west-central Yukon.

Other tephra beds have been found in the Upper White Channel gravel and in the overlying sediments, and offer the potential for additional age control. Little Blanche Creek tephra has been discovered in the Quartz Creek (UT1054, UT1455, Preece et al., 2000) and Hunker Creek drainage basins (UT1623, Fig. 2) but 'chunky glass' has not been found in this pumiceous unit, therefore it is not datable by our glass-ft methods. However, it likely can be dated by the $^{40}Ar/^{39}Ar$ technique because of its abundant hornblende. Fortunately, Paradise Hill tephra (UT1624) is only 5.5 m above Little Blanche Creek tephra at Paradise Hill (Fig. 2) and contains good chunky glass. It occurs in fluvial sand above the Upper White Channel gravel and is overlain by organic-rich silt and colluvial deposits (Fig. 2). Its age is not determined as yet.

DESCRIPTION OF TEPHRA BEDS

The mineralogical and chemical characteristics of Jackson Hill and Mosquito Gulch tephra beds prove them to belong to the type I group, whose source volcanoes are located in the Alaska Peninsula-Aleutian arc region (Fig. 1). Quartz Creek tephra, on the other hand, is of the type II variety and comes from a volcano in the Wrangell volcanic field (also in Fig. 1; Preece et al., 1999; Preece et al., 2000).

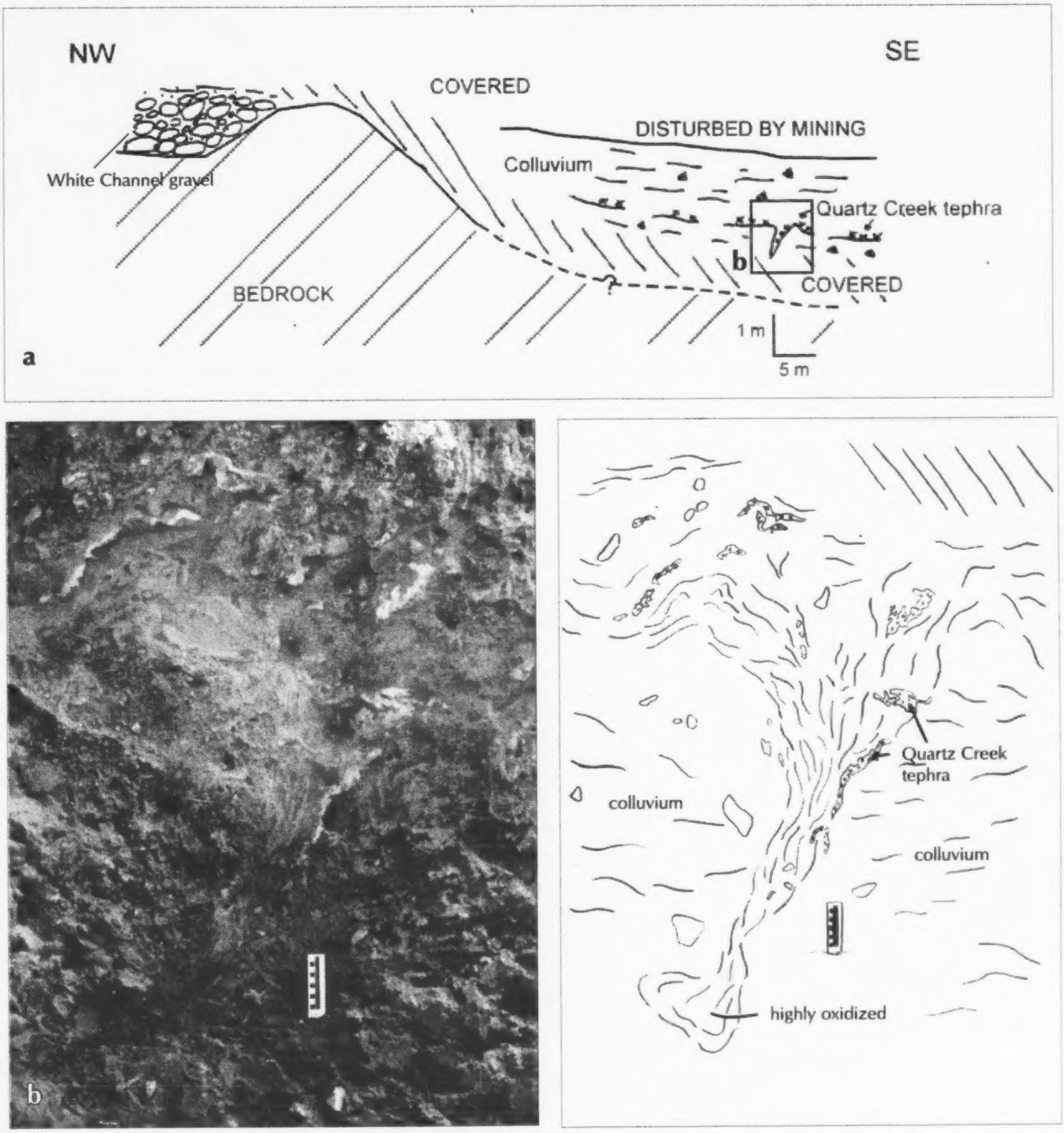
NW
SE
COVERED
DISTURBED BY MINING
Colluvium
White Channel gravel
Quartz Creek tephra
b
COVERED
?
BEDROCK
1 m
5 m
a
b
Quartz Creek tephra
colluvium
colluvium
highly oxidized

Figure 4. *(a) Generalized stratigraphic relationship between Quartz Creek tephra, colluvial sediments, and White Channel gravel at site along Quartz Creek (Fig. 1); (b) Photograph and sketch of Quartz Creek tephra draped within an ice-wedge cast at Quartz Creek site. Dated at 3.00 ± 0.33 Ma, Quartz Creek tephra provides a minimum age for the White Channel gravel in the Klondike region and a late Pliocene age for the first occurrence of permafrost in the Yukon Territory.*

Jackson Hill tephra has a cream colour, whereas Mosquito Gulch tephra is grey. Both consist mostly of bubble-wall glass shards with feldspar, orthopyroxene, clinopyroxene and minor amounts of green or red amphibole, titanomagnetite, ilmenite, apatite and zircon. The white Quartz Creek tephra is very pumiceous and rich in phenocrysts of mostly feldspar, orthopyroxene, green amphibole and iron-titanium oxides; apatite and zircon are rare. All three beds have glass shards of a rhyolitic composition and a homogeneous glass population, although Jackson Hill tephra has the rare dacitic outlier (Table 1, Fig. 5). A unimodal glass composition is an essential prerequisite for glass-ft dating. The trace-element composition of the glass shards is shown in Table 2, where it can be seen that the concentration levels of the rare-earth elements are much lower in Quartz Creek tephra than in the other two units.

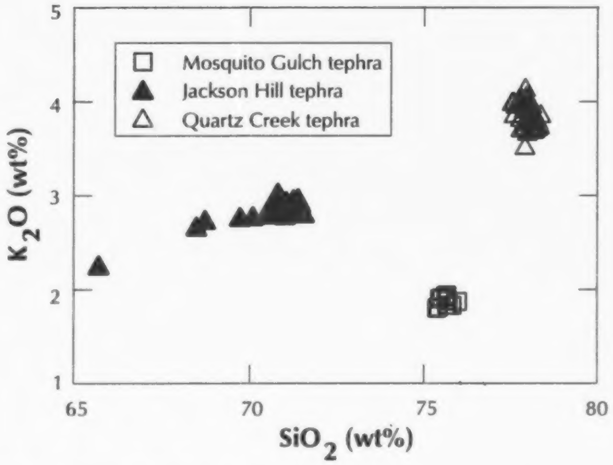

Figure 5. *K_2O/SiO_2 plot showing the homogeneous composition of glass shards in the three tephra beds dated by the glass-ft method.*

FISSION-TRACK DATING

The glass-DCFT method (Sandhu and Westgate, 1995) was used to date the tephra beds, all of which have suffered partial fading of fission tracks in their glass shards (Fig. 6). Correction for this fading effect must be made when determining the glass-ft age of these tephra beds.

An internal standard is included in each irradiation in order to monitor the accuracy of the age determinations. The glass-ft age of Huckleberry Ridge tephra, our internal standard, is very similar to its $^{40}Ar/^{39}Ar$ age (Table 3) and shows that our age estimates are of acceptable accuracy.

Table 1. *Average glass major-element compositions of tephra beds.*

	Quartz Creek		**Jackson Hill**			**Mosquito Gulch**	
			pop. 1	**pop. 2**			
SiO_2	77.96	(0.21)	65.71	70.62	(0.84)	75.63	(0.17)
TiO_2	0.17	(0.06)	0.79	0.61	(0.08)	0.31	(0.09)
Al_2O_3	12.52	(0.16)	15.58	14.74	(0.26)	13.27	(0.09)
FeO_t	0.83	(0.06)	5.24	3.23	(0.26)	1.83	(0.08)
MnO	0.03	(0.02)	0.13	0.11	(0.04)	0.08	(0.04)
CaO	0.93	(0.05)	4.06	2.54	(0.31)	1.34	(0.05)
MgO	0.16	(0.03)	1.62	0.68	(0.13)	0.26	(0.02)
Na_2O	3.52	(0.13)	4.53	4.49	(0.22)	5.24	(0.10)
K_2O	3.84	(0.13)	2.23	2.83	(0.09)	1.87	(0.05)
Cl	0.04	(0.02)	0.11	0.16	(0.03)	0.17	(0.04)
H_2Od	5.06	(0.93)	1.38	2.14	(1.70)	4.97	(1.24)
n	**37**		**1**	**19**		**12**	

Notes: All analyses done on a Cameca SX-50 wave-length dispersive microprobe operating at 15 kV accelerating voltage, 10-15 mm beam diameter, and 6nA beam current. Standardization achieved by use of mineral and glass standards. Analyses recast to 100% on a water-free basis. n = number of analyses, FeO_t = total iron oxide as FeO, H_2Od = water by difference, pop. 1 = population 1, pop. 2 = population 2. Average composition based on non-zero values for the following samples: Quartz Creek (UT1001, UT1053, UT1544), Jackson Hill (UT1562, UT1637) and Mosquito Gulch (UT19). Numbers in brackets are standard deviation.

Table 2. *Average glass trace-element composition of tephra beds.*

	Quartz Creek	Jackson Hill	Mosquito Gulch
Rb	70	67	35
Sr	234	177	77
Y	7	36	37
Zr	94	256	199
Nb	4.0	6.3	4.3
Cs	1.91	3.97	1.53
Ba	873	721	595
La	17.39	18.29	14.69
Ce	30	37	29
Pr	3.39	5.38	4.51
Nd	11.1	22.6	19.2
Sm	1.69	5.73	5.12
Eu	0.62	1.40	1.22
Gd	1.87	6.26	5.43
Tb	0.23	1.03	1.03
Dy	1.21	6.31	6.24
Ho	0.23	1.30	1.34
Er	0.68	3.83	4.11
Tm	0.11	0.62	0.71
Yb	0.75	3.99	4.65
Lu	0.10	0.50	0.57
Hf	2.93	6.56	5.39
Ta	0.40	0.31	0.26
Th	6.9	6.0	2.9
U	2.84	3.17	1.57
n	**6**	**2**	**2**

Notes: Samples were analyzed at the University of Wales, Aberystwyth. Fully quantitative solution ICP-MS analyses were performed using a VG Elemental ICP-MS PlasmaQuad II+ with a modified high sensitivity interface and calibration was achieved using multi-element synthetic standards. Details of the analytical procedures and standards are given in Pearce et al. (1997).
n = number of analyses. Average composition based on the following samples: Quartz Creek (UT1001, UT1053, UT1544), Jackson Hill (UT1562), Mosquito Gulch (UT19).

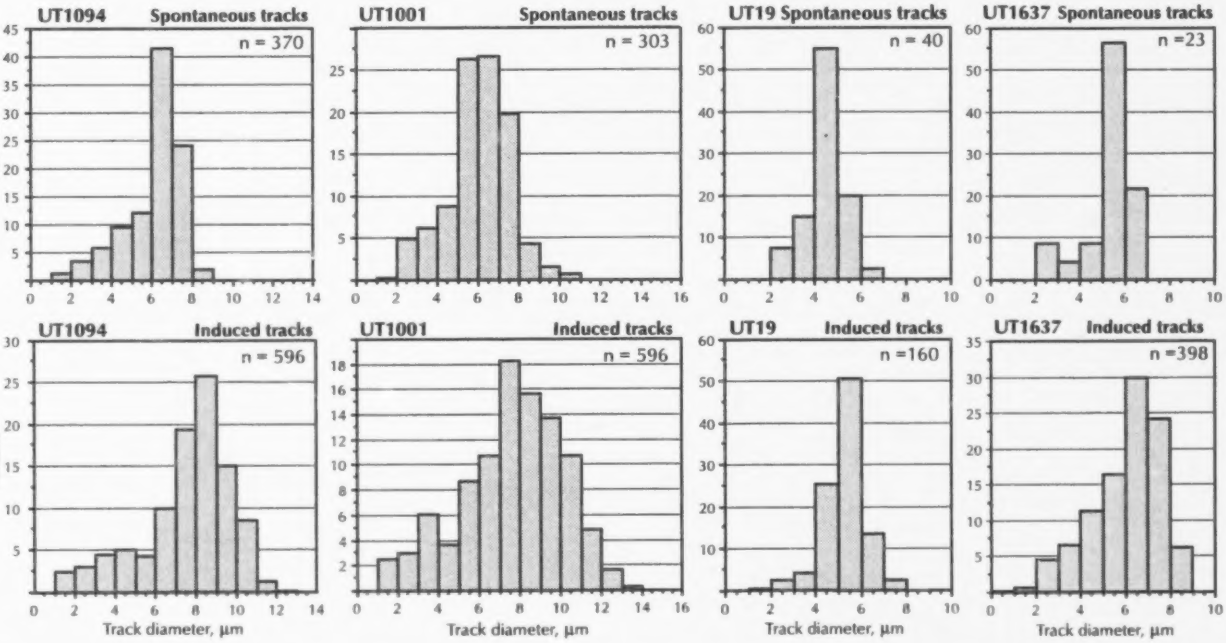

Figure 6. *Size distributions of spontaneous and induced fission tracks in glass shards of dated tephra beds. All samples have experienced partial fading of their spontaneous tracks. Note variation in the vertical scale. UT1094, Huckleberry Ridge tephra, the internal standard; UT1001, Quartz Creek tephra; UT19, Mosquito Gulch tephra; UT1637, Jackson Hill tephra. 'n' is the number of measurements made on each sample.*

Table 3. *Glass-fission-track ages of late Cenozoic distal tephra beds in the Klondike district, Yukon Territory.*

Sample number, Date irradiated, (Analyst)	Spontaneous track density 102 t/cm^2	Corrected spontaneous track density 102 t/cm^2	Induced track density 105 t/cm^2	Track density on muscovite detector over dosimeter glass 105 t/cm^2	Etching conditions HF:temp:time %: O C : s	D_s µm	D_i µm	D_s / D_i or D_i / D_s(#)	Age 10^6 yr
Mosquito Gulch tephra									
UT19 16/05/77 (NN)	3.24 ± 0.64 (26)		0.40 ± 0.02 (635)	4.76 ± 0.05 (9617)	26: 24: 65	nd	nd	nd	1.23 ± 0.25
UT19*		3.86 ± 0.76 (26)	0.40 ± 0.02 (635)	4.76 ± 0.05 (9617)	26: 24: 65	nd	nd	1.19 ± 0.04#$	1.46 ± 0.29*
UT19 16/05/77 (JAW)	3.96 ± 0.67 (35)		0.56 ± 0.01 (2218)	4.76 ± 0.05 (9617)	26: 24: 70	nd	nd	nd	1.06 ± 0.23
UT19*		4.71 ± 0.80 (35)	0.56 ± 0.01 (2218)	4.76 ± 0.05 (9617)	26: 24: 70	nd	nd	1.19 ± 0.04#$	1.26 ± 0.28*
UT19 09/10/98 (AS)	4.25 ± 0.60 (50)		0.57 ± 0.01 (2346)	5.44 ± 0.05 (13889)	24: 23: 70	4.40 ± 0.13	5.23 ± 0.07	0.84 ± 0.03	1.30 ± 0.24
UT19*		5.06 ± 0.72 (50)	0.56 ± 0.01 (2346)	5.44 ± 0.05 (13889)	24: 23: 70	4.40 ± 0.13	5.23 ± 0.07	1.19 ± 0.04#	1.55 ± 0.28*
						Corrected Weighted Mean Age			1.42 ± 0.16*
Quartz Creek tephra									
UT1001 31/01/00 (AS)	39.30 ± 1.96 (401)		2.69 ± 0.02 (14637)	5.01 ± 0.04 (12744)	24: 22: 110	6.01 ± 0.09	7.61 ± 0.10	0.79 ± 0.02	2.36 ± 0.26
UT1001*		49.75 ± 2.5 (50)	2.64 ± 0.02 (14637)	5.01 ± 0.04 (12744)	24: 22: 110	6.01 ± 0.09	7.61 ± 0.10	1.27 ± 0.02#	3.00 ± 0.33*
Jackson Hill tephra									
UT1637 31/01/00 (AS)	1.04 ± 0.23 (21)		1.45 ± 0.02 (5867)	5.06 ± 0.04 (12744)	24: 22: 70	5.31 ± 0.23	6.08 ± 0.08	0.87 ± 0.04	0.12 ± 0.03
UT1637*		1.20 ± 0.26 (21)	1.45 ± 0.02 (5867)	5.06 ± 0.04 (12744)	24: 22: 70	5.31 ± 0.23	6.08 ± 0.08	1.15 ± 0.05	0.13 ± 0.03*
Huckleberry Ridge tephra: internal standard									
UT1094 31/01/00 (JAW)	43.23 ± 1.42 (931)		4.21 ± 0.03 (25152)	4.87 ± 0.04 (12744)	24: 21: 120	6.09 ± 0.07	7.54 ± 0.09	0.81 ± 0.01	1.59 ± 0.17
UT1094*		53.57 ± 1.76 (931)	4.20 ± 0.03 (25152) (12744)	4.87 ± 0.04	24: 21: 120	6.09 ± 0.07	7.54 ± 0.09	1.24 ± 0.02#	1.97 ± 0.21*

Notes

The population-subtraction method was used.

* Samples corrected for partial track fading by the track-size method (Sandhu and Westgate, 1995); uncorrected age is given for the other samples.

Ages calculated using the zeta approach and $\lambda D = 1.551 \times 10^{-10}$ yr^{-1}. Zeta value is 318 ± 3 based on 6 irradiations at the McMaster Nuclear Reactor, Hamilton, Ontario, using the NIST SRM 612 glass dosimeter and the Moldavite tektite glass (Lhenice locality) with an ^{40}Ar/^{39}Ar plateau age of 15.21 ± 0.15 Ma (Staudacher et al., 1982).

Error (± 1σ) is calculated according to Bigazzi and Galbraith (1999). Area estimated using the point-counting technique (Sandhu et al., 1993).

D_s = mean spontaneous track diameter and D_i = mean induced track diameter; nd = not determined. Number of tracks counted is given in brackets.

$ Samples corrected for partial track fading by data from UT19 (AS) because all UT19 age estimates are based on glass shards from the same tephra sample.

Data on UT19 (NN) taken from Naeser et al., 1982. The single-crystal (sanidine) laser-fusion ^{40}Ar/^{39}Ar age of Huckleberry Ridge tephra, the internal standard, is 2.003 ± 0.014 Ma (2σ error) (Gansecki et al., 1998).

# = D_i/D_s

The glass-ft age estimates are given in Table 3. Three separate age determinations were made on Mosquito Gulch tephra and its weighted mean age is 1.42 ± 0.16 Ma. The younger mean age given in Naeser et al. (1982) reflects the fact that no correction was applied for partial track fading, the date being considered as a minimum value. Therefore, Archibald's Bench was formed about 1.4 million years ago, an age that strongly supports correlation to the Midnight Dome Terrace on the Klondike River, just east of Dawson City, given the magnetostratigraphic-based chronology of Froese et al. (2000). The recent identification of Mosquito Gulch tephra near the base of the loess sequence at the Midnight Dome Terrace (Fig. 1) confirms this correlation.

The glass-ft age of Quartz Creek tephra is 3.00 ± 0.33 Ma, which is in agreement with hornblende $^{40}Ar/^{39}Ar$ ages that range from 2.64 Ma to 3.01 Ma (Kunk, 1995) and is compatible with the normal magnetization of the enclosing sediments (Fig. 2, Froese et al., 2000). The authors are currently determining a glass-ITPFT age (Westgate, 1989) for Quartz Creek tephra, which will provide additional control on its age and considerably reduce the relative standard error associated with it. A late Pliocene age for the upper part of the White Channel gravel is confirmed and the presence of Quartz Creek tephra in an ice-wedge cast (Fig. 4) indicates that permafrost conditions existed in west-central Yukon at this time.

Jackson Hill tephra is much younger than was anticipated, given its position near a high-level terrace along the Klondike Valley. It is 0.13 ± 0.03 Ma. Corroborative evidence for this young age comes from its petrographic and chemical attributes that suggest a correlation to VT tephra, which occurs 5 m above Old Crow tephra at Halfway House in central Alaska (Preece et al., 1999).

CONCLUDING STATEMENT

Tephrochronological studies of the late Cenozoic deposits in the Klondike area have only just begun in earnest. The region lies within the fallout zone of large-magnitude volcanic eruptions from the Wrangell Mountains and the Alaska Peninsula-Aleutian arc and already a large number of distal tephra occurrences have been documented, although most await careful study. The results presented in this report give a glimpse of the eventual rewards that tephra studies can confer on our understanding of the late Cenozoic geologic history of the Yukon Territory, namely, the development of a comprehensive, reliable time-stratigraphic framework.

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Geology and alteration signature of a Middle Proterozoic Bear River dyke in the Slats Creek map area, Wernecke Mountains, Yukon (106D/16)

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ABSTRACT

The Middle Proterozoic Bear River dykes (ca. 1.27 Ga) are mafic intrusions that crosscut the Gillespie Lake Group of the Wernecke Supergroup in the Slats Creek and Fairchild Lake map areas (106D/16, 106C/13). The dykes are fine- to medium-grained gabbros and basalts with tholeiitic affinities. The most northwesterly dyke was examined in detail. It was emplaced into mainly dolostone, and crosscuts an older fault. A white-weathering aureole along the margins of the dyke consists of calcite-magnetite-serpentine skarn. Within the dyke, hydrothermal effects are dominated by Fe (hematite and magnetite), with local enrichments of Cu (chalcopyrite) and U, a signature characteristic of earlier-formed zones of Wernecke Breccia (1.6 Ga). Alteration of the dyke indicates that a later pulse of hydrothermal fluids was channelled along the dyke or the fault. The Bear River dykes may belong to the coeval, giant radiating Mackenzie dyke swarm of the northern Canadian Shield.

RÉSUMÉ

Les dykes du Protérozoïque moyen de Bear River (1,27 Ga) sont des intrusions mafiques qui recoupent le Groupe de Gillespie Lake du Supergroupe de Wernecke dans les zones cartographiques de Slats Creek et de Fairchild Lake (106D/16 et 106C/13). Ces dykes sont formés de gabbros et de basaltes de granulométrie fine à moyenne d'affinité tholéiitique. Le dyke situé à l'extrême nord-ouest a été l'objet d'une étude approfondie. Ce dyke, qui s'est mis en place principalement dans des dolomies, recoupe une faille plus ancienne. Une auréole de métamorphisme superficielle de couleur blanche observée le long de la bordure du dyke est composée de skarns à calcite-magnétite-serpentine. Au sein de ce dyke, l'altération hydrothermale est dominée par le fer (hématite et magnétite), accompagné, par endroits, d'enrichissements en cuivre (chalcopyrite) et en uranium, ce qui correspond à une signature caractéristique des zones plus anciennes de la brèche de Wernecke (1,6 Ga). L'altération du dyke indique qu'une arrivée tardive de solutions hydrothermales a eu lieu le long du dyke ou de la faille. Les dykes de Bear River font sans doute partie du gigantesque groupe de dykes de Mackenzie, d'âge équivalent, situé dans la partie septentrionale du Bouclier canadien.

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INTRODUCTION

The Bear River dykes are gabbroic intrusions of Middle Proterozoic age that intrude dolostone and minor mudrock of the Early Proterozoic Wernecke Supergroup (Thorkelson, 2000). The dykes were identified during a regional mapping program from 1992 to 1995 (Thorkelson and Wallace, 1993, 1994). They occur in five localities in the Slats Creek and Fairchild Lake map areas of northeastern Yukon (106D/16, 106C/13), where they crop out as single dykes or swarms of up to eight dykes (Figs. 1, 2). Individual dykes are up to 5 km long, and typically 5-15 m wide. Dyke orientations vary but typically strike northwest. They are commonly flanked by a white-weathering metasomatic contact aureole.

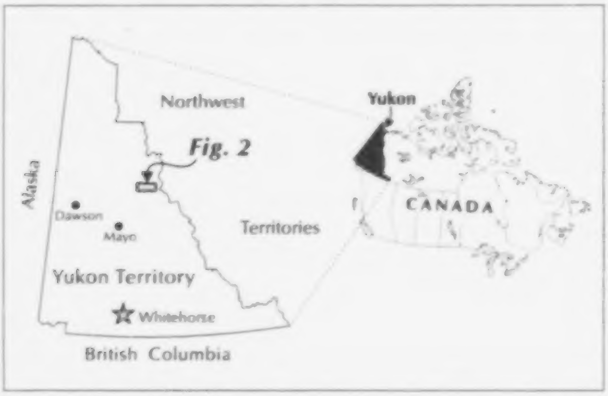
Northwest
Territories
Fig. 2
Alaska
Dawson
Mayo
Yukon Territory
Whitehorse
British Columbia
Yukon
CANADA

Figure 1. *Location map showing region of Bear River dyke exposures in northeastern Yukon (area of Fig. 2).*

The most northwestern occurrence of the Bear River dykes consists of a single intrusion approximately 5 km west of the headwaters of Slats Creek (herein termed the *study area*; Figs. 2, 3). This dyke was dated by U-Pb (baddeleyite) at ca. 1.27 Ga by J.K. Mortensen (pers. comm., 1995; Thorkelson, 2000), and was examined in detail in the summer of 2000. Another Bear River dyke, approximately 16 km east-southeast of the study area, has also been dated at ca. 1.27 Ga by Mortensen (Fig. 2; Thorkelson, 2000). The dyke in the study area is hydrothermally altered and mineralized in a manner similar to the earlier-formed Wernecke Breccias, whose emplacement and main pulse of alteration has been dated at ca. 1.6 Ga (R.A. Creaser, pers. comm., 1994; Thorkelson, 2000). The metasomatic effects in and around the Bear River dyke in the study area represent a younger pulse (≤1.27 Ga) of hydrothermal activity.

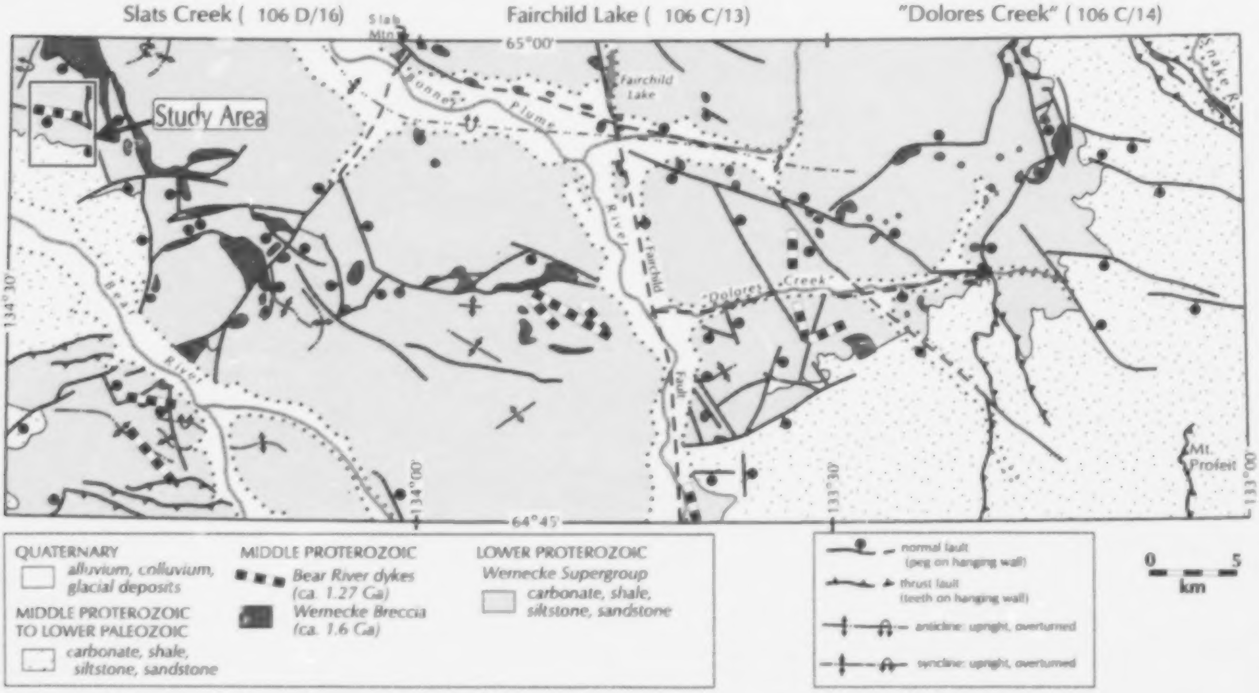
Slats Creek (106 D/16)
Slab Mtn
Fairchild Lake (106 C/13)
"Dolores Creek" (106 C/14)
65°00'
Study Area
Bonnet Plume
Fairchild Lake
Snake R.
Bear River
Fairchild River
Fairchild Fault
"Dolores Creek"
134°30'
134°00'
133°30'
133°00'
64°45'
Mt. Profeit
QUATERNARY
alluvium, colluvium, glacial deposits
MIDDLE PROTEROZOIC TO LOWER PALEOZOIC
carbonate, shale, siltstone, sandstone
MIDDLE PROTEROZOIC
Bear River dykes (ca. 1.27 Ga)
Wernecke Breccia (ca. 1.6 Ga)
LOWER PROTEROZOIC
Wernecke Supergroup
carbonate, shale, siltstone, sandstone
normal fault (peg on hanging wall)
thrust fault (teeth on hanging wall)
anticline: upright, overturned
syncline: upright, overturned
0
5
km

Figure 2. *Simplified geological map of Slats Creek, Fairchild Lake and "Dolores Creek" map areas (106C/13, 106C/14, 106D/16) showing schematic location of Bear River dykes and Wernecke Breccia zones (after Thorkelson, 2000). Study area indicated in northwestern part of map area.*

This report provides an overview of the Bear River dykes, and focuses on the field relations and metasomatic alteration in the study area. Metal enrichments, notably of Cu and U, are characterized using a new method of quantifying geochemical systems including those involving hydrothermal alteration. The dykes are placed in context with the time-equivalent Mackenzie dyke swarm of north-central Canada.

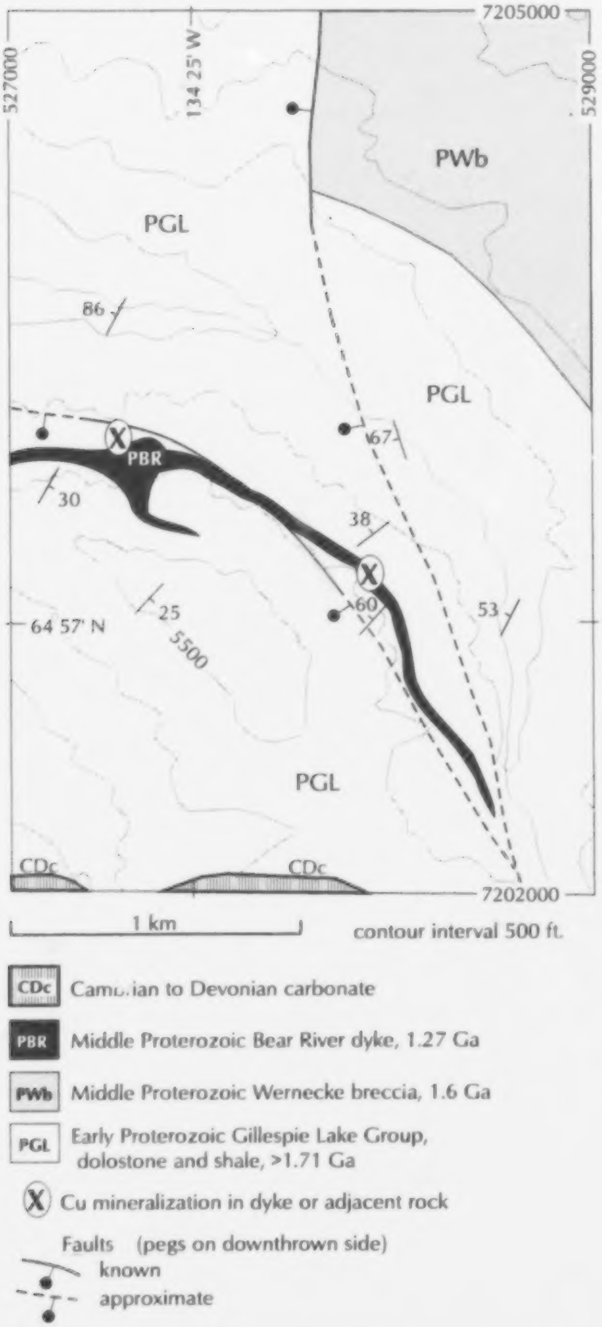
7205000
527000
134 25' W
529000
PWb
PGL
86
PGL
PBR
67
30
38
60
53
25
5500
64 57' N
PGL
CDc
CDc
7202000
1 km
contour interval 500 ft.
CDc Camb.ian to Devonian carbonate
PBR Middle Proterozoic Bear River dyke, 1.27 Ga
PWb Middle Proterozoic Wernecke breccia, 1.6 Ga
PGL Early Proterozoic Gillespie Lake Group, dolostone and shale, >1.71 Ga
Cu mineralization in dyke or adjacent rock
Faults (pegs on downthrown side)
known
approximate

Figure 3. *Simplified geology of the study area, showing Bear River dyke and related Cu-mineralization. Location of study area shown in Figure 2.*

GEOLOGY OF THE STUDY AREA

FIELD RELATIONS AND IGNEOUS MINERALOGY

The Bear River dyke in the study area is approximately 2 km long and pinches and swells in thickness from 0-150 m (Fig. 3). Two or more offshoots extend from the thickest part of the dyke, which is irregularly shaped. The dyke crosscuts orange-weathering dolostone and minor black shale of the Gillespie Lake Group, the highest of the three groups that constitute the Early Proterozoic Wernecke Supergroup (Fig. 4). The dyke strikes east-

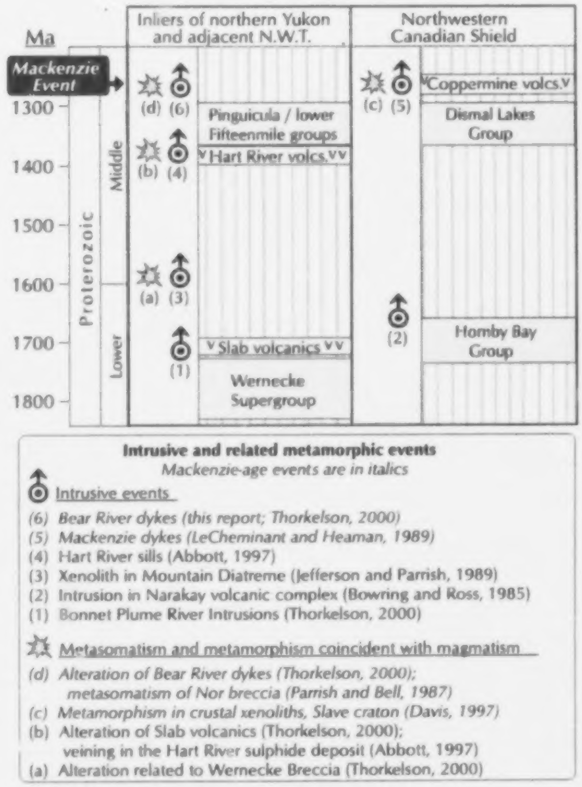
Ma
Mackenzie Event
Inliers of northern Yukon and adjacent N.W.T.
Northwestern Canadian Shield
1300
1400
1500
1600
1700
1800
Proterozoic
Middle
Lower
(d) (6)
(b) (4)
(a) (3)
(1)
(c) (5)
(2)
Pinguicula / lower Fifteenmile groups
Hart River volcs.
Slab volcanics
Wernecke Supergroup
Coppermine volcs.
Dismal Lakes Group
Hornby Bay Group
Intrusive and related metamorphic events
Mackenzie-age events are in italics
Intrusive events
(6) Bear River dykes (this report; Thorkelson, 2000)
(5) Mackenzie dykes (LeCheminant and Heaman, 1989)
(4) Hart River sills (Abbott, 1997)
(3) Xenolith in Mountain Diatreme (Jefferson and Parrish, 1989)
(2) Intrusion in Narakay volcanic complex (Bowring and Ross, 1985)
(1) Bonnet Plume River Intrusions (Thorkelson, 2000)
Metasomatism and metamorphism coincident with magmatism
(d) Alteration of Bear River dykes (Thorkelson, 2000); metasomatism of Nor breccia (Parrish and Bell, 1987)
(c) Metamorphism in crustal xenoliths, Slave craton (Davis, 1997)
(b) Alteration of Slab volcanics (Thorkelson, 2000); veining in the Hart River sulphide deposit (Abbott, 1997)
(a) Alteration related to Wernecke Breccia (Thorkelson, 2000)

Figure 4. *Time-stratigraphic columns of the Yukon and the western Canadian Shield, showing timing of intrusive and metasomatic events (modified from Thorkelson, 2000). Bear River dyking and related metasomatic activity indicated as items (6) and (d), respectively, and correlate with the Mackenzie igneous event.*

southeast, dips steeply to the southwest, and is locally flanked by a 5- to 10-m thick white-weathering contact aureole. Thorkelson and Wallace (1993) indicated that the dyke parallels a fault within the Gillespie Lake Group. Our re-examination indicates that the dyke cuts across the fault at a low angle. The fault is evident from an abrupt change in bedding attitude in the vicinity of the dyke, and is locally marked by zones of coarse red-weathering dolomite spar up to 30 m wide. The spar was apparently deposited in dilatant zones adjacent to the fault surface. The intrusion is medium grained in the centre and fines towards the margins, where it is chilled against the host sedimentary strata.

Inside the chilled margins, the dyke consists of dark greenish-grey weathering, greenish-grey fine- to medium-grained gabbro. The essential igneous mineralogy of the dyke in the study area locality is similar to that of the other Bear River dykes and consists mainly of subequal amounts of plagioclase and clinopyroxene, with accessory magnetite ranging from 1-7%. Interstitial granophyre is commonly present in proportions up to 10% and consists of quartz and alkali feldspar and associated apatite. The igneous mineralogy has been largely supplanted by secondary minerals under conditions of low-grade metamorphism. Plagioclase has altered to clay, mica, calcite, chlorite and epidote, and clinopyroxene has altered to chlorite. Hydrothermal activity has also affected the mineralogy and geochemistry, as described below.

METASOMATIC ALTERATION

Three events of metasomatic activity are recorded in the study area. Subsequent regional metamorphism at sub- to lower-greenschist grades (Thorkelson, 2000) has further affected the rocks. The first metasomatic event occurred during emplacement of a zone of Wernecke Breccia approximately 1 km north of the dyke (Figs. 2, 3, 4, event (a)). The breccia zone and adjacent wall rocks are characterized by disseminations and veins of specular hematite, and other minerals such as quartz, carbonate, feldspar, and minor chalcopyrite. Earlier-formed (1.6 Ga) Wernecke Breccia zones typically host localized enrichments of Cu, Co, U and Au (e.g., Laznicka and Edwards, 1979; Bell, 1986; Hitzman et al., 1992; Thorkelson, 2000), but the Wernecke Breccia zone in the study area was not examined in detail in this investigation, and the degree to which enrichments may exist has not been evaluated.

In the second metasomatic event, dolostone wall rock of the Gillespie Lake Group was thermally and metasomatically altered to skarn by magma of the Bear River dyke. The age of skarnification is, therefore, the same as the age of dyke emplacement, 1.27 Ga (Fig. 4, event (6)). The skarn ranges in thickness from 5 to 10 m and is mainly restricted to the margins of the thickest part of the intrusion (in other localities of the Bear River dykes, skarnification is more continuous). The skarn presently consists of an assemblage of calcite, serpentine, magnetite, and minor chalcopyrite and pyrite. Olivine was probably a primary constituent of the skarn that has since been retrograded to serpentine. The calcite, which comprises 90 to 95% of the skarn, is white-weathering, pale green and fine-grained. Original sedimentary laminations are typically well preserved on weathered surfaces, and are commonly accentuated by thin (1 to 5 mm) layers of serpentine. The serpentine also occurs as veins, pods, and along fractures, some of which are sheared and have slickensides. Magnetite occurs as clots, drusy fracture fillings, disseminations, and intergrowths with serpentine. Chalcopyrite and pyrite occur locally as coarse- to fine-grained clusters and fine disseminations. Malachite grain coatings and fracture fillings occur adjacent to chalcopyrite. In a few localities, irregular veins of specular hematite occur in the skarn, but their origin is ascribed to the third phase of metasomatism.

The third metasomatic event (Fig. 4, event (d)) produced veins, metasomatic bands, and large patches of pervasive alteration in the Bear River dyke. Mineralogical changes of the dyke include alteration of plagioclase feldspar to potassium feldspar (giving the rock a pinkish colour), and growth of chlorite, carbonate, hematite and quartz in veins, and magnetite, hematite, pyrite and chalcopyrite as fine disseminations. These features are very similar to those which occurred during Wernecke Breccia development. The third event also produced sinuous, discontinuous hematite veins from 1 to 7 cm thick, within in the skarn. Beyond the skarn, the country rock shows hematitic and sparry carbonate alteration, but it is unclear what proportion of these features developed during the third event of metasomatism, and how much was produced during the first phase of hydrothermal activity, when the Wernecke Breccias were emplaced and voluminous metasomatic cells permeated the crust.

The age of the third phase of metasomatism occurred, at least in part, after dyke emplacement (≤1.27 Ga). This event may have occurred in response to fluid migration induced by general heating of the country rock during dyke emplacement. In this scenario, the third event would be a localized, late-stage hydrothermal product of Bear River magmatism (Fig. 4). No other cause of the fluid activity has been identified. The localized nature of this hydrothermal event is clear from field relations which reveal that, in other parts of the Wernecke Mountains, metasomatism related to Wernecke Breccia ceased prior to deposition of the Pinguicula Group at ca. 1.38 Ga (Fig. 4; Thorkelson, 2000). No hydrothermal activity that could correlate with the third event in the study area has been found to penetrate the Pinguicula Group. However, limited evidence corroborates the presence of minor hydrothermal activity elsewhere at ca. 1.27 Ga (Fig. 4). In the Richardson Mountains of northern Yukon, hydrothermal monazite in the Nor breccia occurrence was dated at ca. 1.27 Ga by Parrish and Bell (1987). In the Northwest Territories, heating of the middle crust is evident from ages of reset rutile and metamorphic zircon growth in xenoliths, and ascribed to crustal heating during 1.27 Ga Mackenzie magmatism (Davis, 1997). Earlier, at 1.38 Ga, hydrothermal activity at Slab Mountain, approximately 30 km east-northeast of the study area, led to rutile precipitation in a megaclast of volcanic rocks in a zone of Wernecke Breccia dated at 1.6 Ga (Fig. 4; Thorkelson, 2000). This hydrothermal event may have been related to 1.38 Ga magmatism of the Hart River mafic intrusions in the Ogilvie and Wernecke Mountains (Thorkelson, 2000; Abbott, 1997). Taken together, these data suggest that weaknesses in the upper crust occupied by intrusions and breccia zones acted as paths for later hydrothermal activity during subsequent igneous events at 1.38 and 1.27 Ga.

GEOCHEMISTRY

Research-grade geochemical analyses were obtained by X-ray fluorescence and inductively coupled mass spectrometry for 11 samples of the Bear River dykes from all 5 of the dyke localities. In addition, assays for a broad range of metals, including gold, were determined for six samples. All of the data is provided in Tables 1, 2 and 3. Geochemical analyses for five of the samples were originally reported by Thorkelson (2000).

IGNEOUS GEOCHEMISTRY

Major and trace element geochemistry is given in Table 1. Magnesium numbers (Mg#) calculated using $[100Mg^{2+}/(Mg^{2+}+Fe^{2+})]_{atomic}$ based on $(Fe^{3+}/Fe^{2+})_{atomic} = 0.117$, range from 42 to 59. These quotients are far below the minimum value of 72 for primary mantle melts, and indicate that the Bear River magmas are geochemically evolved. Most of the samples are quartz normative with the exception of three samples, which are olivine normative. Preliminary analysis indicates that the dykes have a tholeiitic affinity, are compositionally categorized as basalts to basaltic andesites, and have major and trace element abundances similar to those of continental flood basalts. Details of igneous petrology and geochemistry will be published elsewhere.

Table 1. *Major oxides – analyses obtained by X-ray fluorescence and reported on a volatile-free basis.*

Sample no.			Lab	Location			SiO_2	TiO_2	Al_2O_3	FeO*	MnO	MgO	CaO	Na_2O	K_2O	P_2O_5	Mg #
Geol	Yr	Number	Sample#	NTS	UTM E	UTM N	wt %	wt %	wt %	wt %	wt %	wt %	wt %	wt %	wt %	wt %	
TOA	96	6-7-2B	6-7-2B	106D/16	527600	7203300	54.3	1.05	14.2	10.7	0.20	7.20	7.83	2.17	2.16	0.11	58
DT	96	1-1-1B	1-1-1B	106C/13	563700	7181700	51.8	2.29	12.0	14.9	0.31	6.93	6.73	3.86	0.99	0.21	49
DT	92	11-1B	G-2	106D/16	532000	7186800	53.5	1.09	13.4	11.4	0.15	8.05	6.74	2.21	3.24	0.12	59
CW	93	19-1B	G-125	106C/13	556900	7192900	48.8	1.30	12.7	17.0	0.16	6.19	9.48	1.61	2.65	0.14	42
DT	93	72-1B	G-112	106C/13	569600	7196900	51.9	2.28	13.1	14.0	0.23	5.89	8.34	2.91	1.11	0.23	46
DS	00	2-2-8B	2-2-8B	106D/16	528500	720300	55.6	1.18	14.0	12.12	0.21	6.67	6.50	2.23	1.36	0.13	53
DS	00	2-2-9B	2-2-9B	106D/16	528500	720300	63.6	1.54	12.9	6.98	0.13	6.28	1.58	0.06	6.63	0.28	65
DS	00	3-1-1B	3-1-1B	106D/16	527500	720350	65.1	0.48	10.7	12.13	0.13	7.10	1.45	-0.01	2.65	0.28	54
DS	00	3-1-2B	3-1-2B	106D/16	527500	720350	58.6	0.44	10.2	6.86	0.11	6.45	12.18	0.79	4.25	0.12	66
DS	00	3-2-1B	3-2-1B	106D/16	527500	720350	55.5	1.38	17.5	8.76	0.18	6.25	3.39	0.14	6.66	0.15	59
DS	00	3-2-5B	3-2-5B	106D/16	527500	720350	55.7	1.15	14.5	10.54	0.20	5.83	7.85	2.55	1.52	0.12	53

Table 2. *Trace elements from inductively coupled mass spectrometry and X-ray fluorescence on pressed powders.*

Sample	Ba	Rb	Cs	Th	Ta	U	Nb	La	Ce	Pb	Sr	Pr	Nd	Zr	Sm	Hf	Eu	Gd	Tb	Dy	Ho
No.	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm
6-7-2B	387	76.0	1.89	4.08	0.47	0.87	7.70	15.8	32.7	5	145.5	3.33	15.3	100	3.47	2.94	1.09	3.80	0.66	3.69	0.72
1-1-1B	238	24.2	0.86	1.75	0.54	0.49	9.53	11.8	29.8	-5	122.6	3.40	17.4	122	4.85	3.77	1.85	5.10	0.80	4.84	0.89
11-1B	268	164.7	5.72	2.81	0.52	0.68	6.44	13.0	27.3	21.69	102.8	3.25	13.8	73	3.15	2.22	0.96	3.50	0.50	3.36	0.62
19-1B	431	35.3	0.90	4.36	1.09	1.93	15.01	21.9	49.3	15.73	294.5	5.95	22.3	113	4.77	3.55	1.43	4.78	0.71	4.26	0.84
72-1B	332	25.2	2.57	1.81	0.59	1.04	10.30	12.5	31.6	22.94	256.0	4.42	20.2	137	5.28	3.82	1.84	6.18	0.86	5.23	0.97
2-2-8B	240	32.7	na	4.26	na	2.81	8.00	na	53.4	7.36	93.7	na	na	105	na	na	na	na	na	na	na
2-2-9B	615	106.7	na	13.01	na	3.53	16.13	na	47.5	6.71	22.2	na	na	218	na	na	na	na	na	na	na
3-1-1B	218	35.6	na	9.69	na	14.81	12.67	na	216.2	-3.68	8.5	na	na	138	na	na	na	na	na	na	na
3-1-2B	730	111.5	na	6.87	na	6.93	10.98	na	44.7	-7.35	36.4	na	na	120	na	na	na	na	na	na	na
3-2-1B	3561	102.9	na	2.29	na	5.81	8.75	na	-40.1	-2.56	81.1	na	na	123	na	na	na	na	na	na	na
3-2-5B	323	41.4	na	6.26	na	3.07	9.13	na	24.2	-3.59	157.5	na	na	118	na	na	na	na	na	na	na

Sample	Er	Tm	Y	Yb	Lu	V	Sc	Cr	Co	Ni	Ga	Cu	Zn	Be	Li	Tl	Bi	Ag	Sn	Sb
No.	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm
6-7-2B	2.20	0.29	21	2.15	0.32	263	na	357	69.8	162	na	122	50	na	na	0.35	0.81	-0.50	0.80	2.09
1-1-1B	2.53	0.35	25	2.26	0.32	369	na	129	69.9	678	na	354	267	na	na	1.05	0.17	-0.50	1.10	2.58
11-1B	1.86	0.25	15.5	1.63	0.24	284	31.3	479	41.5	151	na	142	102.0	0.54	32.06	0.62	0.26	0.66	35.58	7.39
19-1B	2.20	0.31	19.2	2.04	0.29	238	25.8	208	33.8	82	na	70	120.6	0.54	27.33	0.30	0.05	1.44	1.95	2.40
72-1B	2.58	0.37	23.4	2.05	0.29	419	28.2	109	45.6	78	na	371	156.4	1.50	17.36	0.19	0.05	0.95	1.66	1.19
2-2-8B	na	na	17.7	na	na	292	29.0	331	na	84	16.2	167	30.4	na	na	na	na	na	na	na
2-2-9B	na	na	26.7	na	na	262	28.9	5	na	23	16.7	338	104.3	na	na	na	na	na	na	na
3-1-1B	na	na	17.6	na	na	126	2.0	48	na	19	13.8	5135	78.6	na	na	na	na	na	na	na
3-1-2B	na	na	22.5	na	na	203	8.7	46	na	112	9.8	501	0.3	na	na	na	na	na	na	na
3-2-1B	na	na	12.0	na	na	369	44.7	471	na	134	14.1	305	67.5	na	na	na	na	na	na	na
3-2-5B	na	na	21.0	na	na	285	25.6	289	na	87	18.8	101	15.7	na	na	na	na	na	na	na

na = not analyzed

Table 3. *Assays by inductively coupled mass spectrometry except for gold, obtained by fire assay and atomic absorption.*

Sample	Au	Ag	Al	As	Ba	Be	Bi	Ca	Cd	Co	Cr	Cu	Fe	Hg	K	Mg	Mn	Mo
No.	ppb	ppm	%	ppm	ppm	ppm	ppm	%	ppm	ppm	ppm	ppm	%	ppm	%	%	ppm	ppm
2-2-8B	5	<1	3.49	10	<20	<5	<10	2.71	<5	45	210	200	7.37	<10	0.12	3.03	1190	<5
2-2-9B	<5	<1	2.46	<10	120	<5	<10	1.1	<5	40	<10	360	5.33	<10	0.09	4.08	870	<5
3-1-1B	<5	2	3.76	<10	<20	<5	<10	1	<5	25	40	5950	9.28	<10	0.06	4.31	870	<5
3-1-2B	<5	1	1.59	30	320	<5	<10	8.33	<5	120	30	640	4.32	<10	0.56	2.44	650	15
3-2-1B	10	1	2.97	<10	3320	<5	<10	2.35	<5	55	340	365	6.17	<10	0.47	3.93	1250	<5
3-2-5B	<5	1	2.38	<10	40	<5	<10	1.79	<5	35	160	110	4.61	<10	0.17	1.82	700	<5
4-3-1B	<5	1	2.14	<10	20	<5	<10	1.32	<5	20	60	165	2.76	<10	0.08	0.95	250	<5

Sample	Na	Ni	P	Pb	Sb	Sc	Sr	Ti	Tl	U	V	W	Zn
No.	%	ppm	ppm	ppm	ppm	ppm	ppm	%	ppm	ppm	ppm	ppm	ppm
2-2-8B	0.1	105	400	15	<10	5	45	0.31	<20	20	180	<20	60
2-2-9B	0.09	50	1100	15	<10	15	10	0.03	<20	<20	200	<20	165
3-1-1B	0.09	50	1000	<5	<10	<5	15	0.01	20	<20	100	<20	130
3-1-2B	0.11	140	400	<5	<10	5	25	0.11	<20	20	140	<20	30
3-2-1B	0.1	185	500	25	<10	25	85	0.03	<20	20	240	<20	120
3-2-5B	0.12	85	500	5	<10	<5	25	0.34	<20	<20	140	<20	30
4-3-1B	0.38	45	300	5	10	<5	25	0.13	<20	<20	120	<20	20

METASOMATISM EVALUATED WITH STONERGRAMS

The geochemical signature of metasomatism of the Bear River dykes has been evaluated by comparing major oxide and selected element abundances of metasomatized samples to that of the least-altered dyke sample (sample TOA-96-6-7-2B). The comparison has been made using a new type of graphical display, herein called *Stonergrams* (Fig. 5). The numerical method for Stonergrams is based on the same logic used in the construction of Pearce Element Ratio diagrams (Pearce, 1968), and the Isocon diagram (Grant, 1986), but the results are shown in a familiar Spider Diagram-like display. For each sample, the abundances of oxides and elements are divided by the concentration of a suspected immobile component (in this case, Al_2O_3 was used). The quotients obtained for metasomatized samples are then divided by the quotient for the non-metasomatized sample. The resultant Stonergram displays the enrichment or depletion of each component on a logarithmic scale. If, for example, Na_2O for a metasomatized sample plots with a value of 10, then metasomatism has (at face value) enriched Na_2O in that sample to ten times its original composition. If the value of Na_2O for an altered rock lies at 0.25, then only one-quarter of the Na_2O remains, meaning that metasomatism has removed 75% of the original Na_2O. If Na_2O plots with a value of 1, then it has been neither enriched nor depleted. A major assumption in this analysis is that the composition of all samples was nearly identical prior to metasomatic alteration. Details and pitfalls of the method will be published elsewhere.

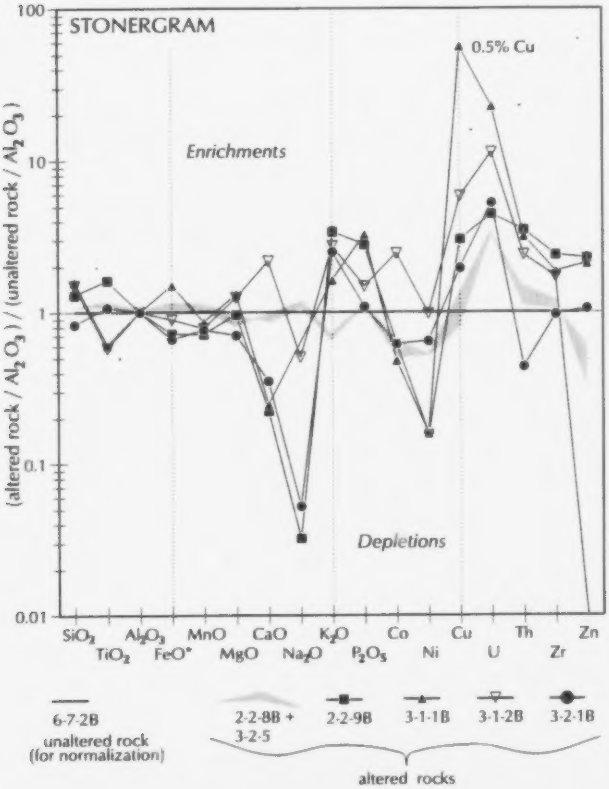

Figure 5. *Stonergram indicating metasomatic alteration in six samples of the Bear River dyke, compared to a relatively unaltered sample, and normalized to alumina. See text for interpretation and methodology.*

In the Stonergram (Fig. 5), the major oxides SiO_2, TiO_2, FeO*, MnO and MgO in all metasomatized samples show modest enrichments or depletions relative to 'unaltered' sample 6-7-2B (FeO* = total Fe as FeO). In most samples, SiO_2 is elevated, demonstrating a general trend toward silica metasomatism. The remaining oxides, CaO, Na_2O, K_2O and P_2O_5, and trace elements Co to Zn, display greater variability and indicate pronounced mobility. Overall, the least-altered compositions are those of samples 2-2-8 and 3-2-5, whose combined range of variability is represented by a shaded pattern. This pattern shows little enrichment or depletion in the major oxides and trace elements, except for U, which is elevated approximately four times above normal, and Zn, which is depleted. The remaining four metasomatized samples show greater chemical variability and have experienced significant losses or gains in CaO, losses of Na_2O, and gains of K_2O and P_2O_5. In addition, some of the samples show pronounced enrichments or depletions of trace elements, particularly in Ni, Cu, U, Th, and Zn. In two of the samples, significant depletions in Ni are paired with enrichments in Cu. The most Cu-enriched sample contains approximately 5000 ppm (0.5%) Cu as chalcopyrite and malachite (Table 3).

Altogether, the metasomatism may be broadly described as one of silica-potassium alteration, with concomitant losses in sodium and calcium, gains in uranium, thorium and phosphorous, and striking, localized enrichments of copper. Gold, silver, and a variety of other elements were not significantly enriched (Tables 1-3). The trend toward potassium enrichment is consistent with K-feldspar replacement of plagioclase, which is evident petrographically. The absence of consistently elevated FeO* concentrations is surprising, given the abundance of hematite mineralization in much of the study area. Nevertheless, the sample with the greatest Fe-enrichment also displays the greatest gains in Cu and U. The metasomatic effects on the Bear River dyke in the study area are similar to those in some zones of Wernecke Breccia, particularly the local enrichments of Cu and U. However, enrichments of Co, Au, Ag and Mo, which also occur locally in Wernecke Breccia, were not identified in the dyke.

REGIONAL SIGNIFICANCE

The preliminary U-Pb dates of ca. 1.27 Ga for the Bear River dykes indicates that the dykes are coeval and perhaps comagmatic with the 1.27 Ga Mackenzie igneous event (Francis, 1994; Baragar et al., 1996). This event includes the 1270+4 Ma Muskox layered intrusion, the 1267+2 Ma Mackenzie dyke swarm, and their extrusive equivalent, the Coppermine River continental tholeiitic basalts (LeCheminant and Heaman, 1989), located more than 1500 km to the east in the Canadian Shield. The Mackenzie dykes make up the world's largest continental dyke swarm (Ernst et al., 1995), radiating from western Victoria Island to the Arctic Coast through the Northwest Territories, southeastward into Nunavut, and southward for more than 2000 km into Ontario (Fig. 6). The western extent of the swarm is obscured beneath sedimentary cover, and may be evident only in localities such as the study area where the age of exposed strata exceeds 1.27 Ga.

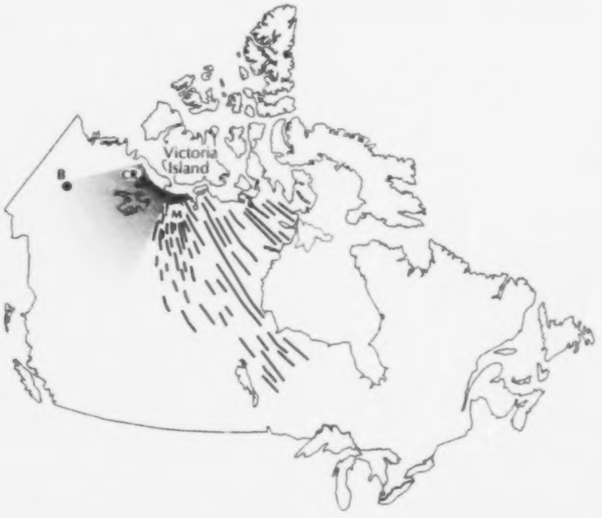

Figure 6. *Principal features of the Mackenzie igneous event. Mackenzie dykes are shown as thick lines (after Fahrig, 1987; Hoffman, 1989). CR = Coppermine River basalts; M = Muskox intrusion; B = location of Bear River dykes. Shaded area indicates possible westward continuation of dyke swarm.*

The large volume of magma emplaced over a relatively short time period (a few million years), and the radiating nature of the Mackenzie dykes, lead LeCheminant and Heaman (1989) to propose a mantle plume origin for the magmas with a focus on Victoria Island. The predicted trend of Mackenzie dykes in the study area, based on radiation of dykes from this focus, would be approximately northeast. The lack of concordance between this expected trend and the orientation of the Bear River dykes (which strike mainly northwestward), may be explained by the location of the Bear River dykes in the Cordilleran orogen which developed after the Mackenzie event, mainly in Mesozoic and early Tertiary times. In and near the study area, post-Mackenzie tectonic events include contractional, extensional and strike-slip deformation (Green, 1972; Norris and Dyke, 1997; Thorkelson, 2000). These events may have caused crustal block rotations and reorientation of the Bear River dykes from trends originally concordant with the radiating Mackenzie pattern. Alternatively, crustal features and a local stress field may have controlled the orientation of the dykes during emplacement. Pehrsson et al. (1993) identified a Mackenzie dyke 1000 km from the proposed focal point that trends perpendicular to the main trend of the Mackenzie dyke swarm. They speculated that the similar-trending Great Slave Lake shear zone in the Slave craton may have controlled the orientation of the dyke, or that changes in the local stress regime at the time of emplacement affected the orientation of the intrusions.

If the Bear River dykes are indeed part of the Mackenzie dyke swarm, then the demonstrated radius of the dyke swarm would be increased by over 50 degrees, expanding the recognized arc of the swarm by 50% (Fig. 6). Correlation between the Bear River dykes and the Mackenzie dyke swarm will be further explored using geochemistry and additional geochronology.

CONCLUSIONS

The Bear River dyke in the study area has undergone extensive hydrothermal alteration at, or after, 1.27 Ga. The alteration may be generally characterized by enrichments in silica, potassium, phosphorous, copper, uranium, and thorium, and depletions of sodium, calcium, and nickel. Although iron enrichments are not ubiquitous, growth of hematite in veins and as disseminations is common. These characteristics are similar to those developed in the Wernecke Breccias at ca. 1.6 Ga, and appear to represent a secondary pulse of fluids with similar compositions. Skarn is well developed in parts of the dolostone host-rock flanking the dyke. The dolostone was altered to an assemblage of calcite-olivine-magnetite, and the olivine has since been retrograded to serpentine. The Bear River dykes may belong to the giant radiating Mackenzie dyke swarm. If so, they represent Mackenzie magmatism far to the west (>1500 km) from its currently identified western limit in the western Canadian Shield. Thus, the arc of the swarm may have been at least 50 degrees larger, and 50% greater, than previously thought.

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PROPERTY DESCRIPTIONS

Geology of the Wolverine polymetallic volcanic-hosted massive sulphide deposit,
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Geology of the Wolverine polymetallic volcanic-hosted massive sulphide deposit, Finlayson Lake district, Yukon Territory, Canada[1]

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ABSTRACT

The Wolverine polymetallic volcanic-hosted massive sulphide deposit occurs in a highly deformed but coherent stratigraphic succession of early Mississippian to early Permian metavolcanic and metasedimentary rocks of the Yukon-Tanana Terrane. The deposit is part of the emerging Finlayson Lake volcanic-hosted massive sulphide district and contains a geological resource of 6,237,000 tonnes grading 12.66% zinc, 1.33% copper, 1.55% lead, 370.9 g/t silver and 1.76 g/t gold. Local stratigraphy consists of four major units including (from oldest to youngest): (1) quartz- and feldspar-phyric volcaniclastic, carbonaceous sedimentary and porphyritic intrusive rocks; (2) interbedded argillite, aphyric rhyolite and magnetite-carbonate-pyrite exhalite; (3) fragmental rhyolite; and (4) interbedded carbonaceous argillite, greywacke, basalt and rhyolite. The mineralization consists of pyrite and sphalerite, with lesser pyrrhotite, chalcopyrite, galena, tetrahedrite-tennantite and arsenopyrite. Mineralization occurs as massive stratiform, massive replacement and sulphide stringer veins. Sulphides are typically massive, fine-grained, layered and locally brecciated. Styles of hydrothermal alteration identified in the host rocks include proximal silicification and more distal chloritization, sericitization and, in places, carbonatization. Future research will be focussed on identifying the salient physico-chemical controls on the mineralization process and their implications for volcanic-hosted massive sulphide exploration in the district and elsewhere.

RÉSUMÉ

Le gisement de sulfure massif volcanogène polymétallique de Wolverine est logé dans une succession stratigraphique fortement déformée mais concordante, composée de roches méta-volcaniques et méta-sédimentaires du terrane de Yukon-Tanana, d'âge Mississippien précoce à Permien précoce. Ce gisement est situé dans le district minier émergent de Finlayson Lake; il contient une ressource géologique de 6 237 000 tonnes de minerai ayant une teneur de 12,66% de zinc, 1,33% de cuivre, 1,55% de plomb, 370,9 g/t d'argent et 1,76 g/t d'or. La stratigraphie locale comprend quatre unités majeures (en ordre d'âge décroissant) : (1) roches volcaniclastiques à porphyres de quartz et feldspaths, roches sédimentaires carbonées et intrusions porphyritiques; (2) interstratifications d'argilite, de rhyolite aphanitique et de roches exhalatives à magnétite, carbonate et pyrite; (3) rhyolite bréchique; et (4) interstratifications d'argilite carboné, de grauwacke, de basalte et de rhyolite. Le minerai se compose de pyrite et de sphalérite, et de quantités moindres de pyrrhotite, chalcopyrite, galène, tetrahédrite-tennantite, et arsénopyrite. La minéralisation est présente sous forme de veines massives stratiformes, de remplacements massifs, et de veinules de sulfures. Les sulfures sont généralement massifs, à grains fins, laminés et, localement, bréchiques. Les types d'altération hydrothermale reconnus dans les roches encaissantes comprennent une silicification proximale, une chloritisation et sericitisation plus distales, et une carbonatisation localisée. Les études à venir seront concentrées sur l'identification des principaux facteurs physico-chimiques contrôllant les processus de minéralisation et leurs influence sur l'exploration pour des sulfures massifs volcanogènes dans cette région et ailleurs.

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INTRODUCTION

The discovery of the Wolverine polymetallic volcanic-hosted massive sulphide (VHMS) deposit in 1995 was one of the most exciting events on the Canadian exploration scene in the mid-1990s. Its discovery, together with that of several other base metal deposits and mineral occurrences of potential economic significance (e.g., Fyre Lake, Ice, GP4F, Kudz Ze Kayah) heralded the emergence of the Finlayson Lake area in the Yukon as a potentially significant VHMS district. As of 1998, the Wolverine deposit contains a high-grade geological resource of 6,237,000 tonnes containing 12.66% zinc, 1.33% copper, 1.55% lead, 370.9 g/t silver and 1.76 g/t gold. Drilling in 2000 modestly expanded this geological resource and the deposit remains open at depth. Exploration efforts in and around the Wolverine deposit by joint-venture partners Expatriate Resources Limited (Expatriate) and Atna Resources Limited (Atna) continue, with the ultimate aim of expanding the existing resource and defining new areas of VHMS potential.

The discovery of significant VHMS mineralization in the Finlayson Lake district has provided the impetus to better understand the tectonic and geological history of the area. Regional geological mapping by the Yukon Geology Program was initiated in 1996 and results are summarized in Murphy and Timmerman (1997), Murphy (1998), and Murphy and Piercey (1999a,b,c). Tectonic and metallogenic studies conducted under the auspices of the Geological Survey of Canada's (GSC) National Mapping program (NATMAP) were initiated in 1999 (Thompson et al., 2000). More recently, another GSC project to study the characterization and genesis of VHMS deposits in the district was initiated. The present study forms part of this last project.

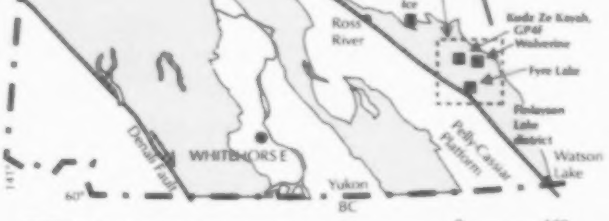

Figure 1. Location map of the Yukon-Tanana Terrane (YTT), the Finlayson Lake district and the Wolverine deposit, plus other significant VHMS deposits in the Finlayson Lake district (from Piercey and Murphy, 2000). Location of Fig. 2 is also shown.

In this contribution, we briefly review the exploration history of the Wolverine discovery, and update and expand upon the geological setting and field characteristics of the Wolverine VHMS deposit as outlined in Tucker, et al. (1997). In particular, we focus on the major host lithology, the types and styles of mineralization present, and the related hydrothermal alteration. Preliminary interpretations of the tectonic setting and mode of emplacement are presented.

EXPLORATION HISTORY

Due to its geographic isolation, the metallogenic potential of the area hosting the Wolverine deposit was virtually unknown until the 1970s and early 1980s, when exploration by the Finlayson Joint Venture exploration syndicate (a consortium managed by Archer, Cathro & Associates (1981) Limited) identified numerous, strong, multi-element, geochemical anomalies in soils over a gossanous area devoid of vegetation (termed the "Fetish showing"). Two small-diameter core holes were drilled in 1974 to test this geochemical anomaly, and both intersected low-grade copper- and zinc-sulphide mineralization up dip of the present Wolverine deposit. Despite this discovery of base metal mineralization, the claims were allowed to lapse.

Equity Engineering Limited (Equity) showed renewed interest in the area in 1993 after concluding that the region held promise for hosting VHMS-style mineralization based on favourable stratigraphy and the presence of surficial geochemical anomalies. On behalf of Atna, Equity staked claims over the deposit area and carried out a field exploration program, which consisted of geological mapping, prospecting, and rock/soil sampling. In 1995, Westmin Resources Limited (Westmin) optioned the property from Atna and undertook a vigorous exploration program designed to evaluate the mineral potential of favourable volcanic stratigraphy, which had a strike-length in excess of 10 km. Exploration activity consisted of detailed geological mapping and systematic grid-soil sampling. This fieldwork led to the identification of several additional multi-element geochemical anomalies. The strongest of these was in the area of the original Fetish showing, which was subsequently renamed the "Wolverine zone".

A diamond-drilling program by Westmin in August, 1995 intersected massive sulphide mineralization in the Wolverine zone in the first hole. The first follow-up drill hole, completed in early September of 1995, intersected 8.4 m of massive sulphide mineralization grading 7.63 g/t gold, 1358.3 g/t silver, 0.56% copper, 3.45% lead and 14.22% zinc. The discovery merited extensive drilling in the fall of 1995, and in the following summers of 1996 and 1997. After the 1997 program, 71 drill holes had intersected the mineralization and Westmin calculated a resource of 6,237,000 tonnes grading 12.66% zinc, 1.33% copper, 1.55% lead, 370.9 g/t silver and 1.76 g/t gold (Tucker et al., 1997). The deposit was defined over a strike length of approximately 750 m and remained open down dip to the northeast where it crossed onto the WOL claims owned by Cominco Limited (Cominco).

In 1996, Westmin carried out metallurgical testing on the Wolverine sulphide mineralization. Results in late 1997 confirmed the presence of unusually high levels of selenium (average of 1035 ppm Se, Expatriate Resources, 2000, unpublished data), a deleterious contaminant, which could significantly impact the saleability of the mineral concentrates. Further investigations of the problem, however, were terminated by the takeover of Westmin by Boliden Limited (Boliden) in early 1998. Following the takeover, Expatriate concluded a letter of agreement to purchase Boliden's interests in the Wolverine Project and by June 1999, a new Wolverine Joint Venture (Expatriate and Atna) announced that it was beginning an evaluation of alternative metallurgical methods for processing the sulphides.

In March 2000, Expatriate reached an agreement with Cominco to purchase Cominco's Finlayson Lake assets including the WOL claims immediately adjoining the Wolverine deposit. Metallurgical studies demonstrated that blending the ore from the Wolverine deposit with that from the newly acquired Kudz Ze Kayah deposit would dilute the selenium content to an acceptable level. Drilling programs by Expatriate in July, August, and October, 2000 expanded the existing resource and further defined the known mineralization on the Wolverine property.

REGIONAL GEOLOGY

The Yukon-Tanana Terrane (YTT) is an extensive, elongate, autochthonous terrane, which underlies much of the Yukon and Alaska and is one of the innermost terranes of the Canadian Cordillera (Fig. 1). The YTT is bounded to the northeast by rocks of the North American continental margin and to the southwest by rocks of Stikinia and Slide Mountain terranes. This complex, heterogeneous terrane of pericratonic origin is interpreted to be a Late Devonian to Early Jurassic composite arc sequence underlain by pre-Devonian sedimentary rocks of continental affinity (Mortensen, 1992). The rocks that host the Wolverine deposit are bounded to the northeast by the Finlayson Lake fault zone and to the southwest by the Tintina Fault, along which approximately 450 km of dextral offset (e.g., Mortensen, 1992) has separated this zone from the main portion of the YTT (Fig. 1).

The following summary of the regional geological setting of the Wolverine deposit comes mainly from the work of Murphy (1998), and Murphy and Piercey (1999a,b). Murphy (1998) placed the Fyre Lake, Kudz Ze Kayah and Wolverine VHMS deposits in a highly deformed but coherent stratigraphic succession of early Mississippian to early Permian metamorphosed plutonic, volcanic, and sedimentary rocks (Fig. 2). An angular unconformity separates a lower sequence of polydeformed felsic and mafic metavolcanic rocks, carbonaceous metaclastic rocks, marble and granitic orthogneiss (termed the "Grass Lakes succession") from a younger sequence consisting primarily of carbonaceous metaclastic rocks and quartz- and feldspar-phyric felsic metavolcanic rocks (termed the "Wolverine succession"; Fig. 3). It is the lower sequence that hosts the Kudz Ze Kayah, Fyre Lake and GP4F deposits. A possible second unconformity separates the Wolverine succession from the overlying Campbell Range succession, the latter of which is composed primarily of massive meta-basalt (Fig. 3).

In the immediate vicinity of the Wolverine deposit, three units are mapped (note that although all rocks are metamorphosed, the prefix "meta" is omitted from all rock names for purposes of simplicity). These units are (from oldest to youngest): Unit 5 – a sequence of carbonaceous phyllite, sandstone, conglomerate, muscovite-quartz phyllite, and quartz- and feldspar-phyric porphyry; Unit 6 – interbedded carbonaceous phyllite and siliceous rock; and Unit 7 – carbonaceous phyllite, greywacke, pale green argillite, gritty sandstone, chert and diamictite. The Wolverine deposit lies at the contact

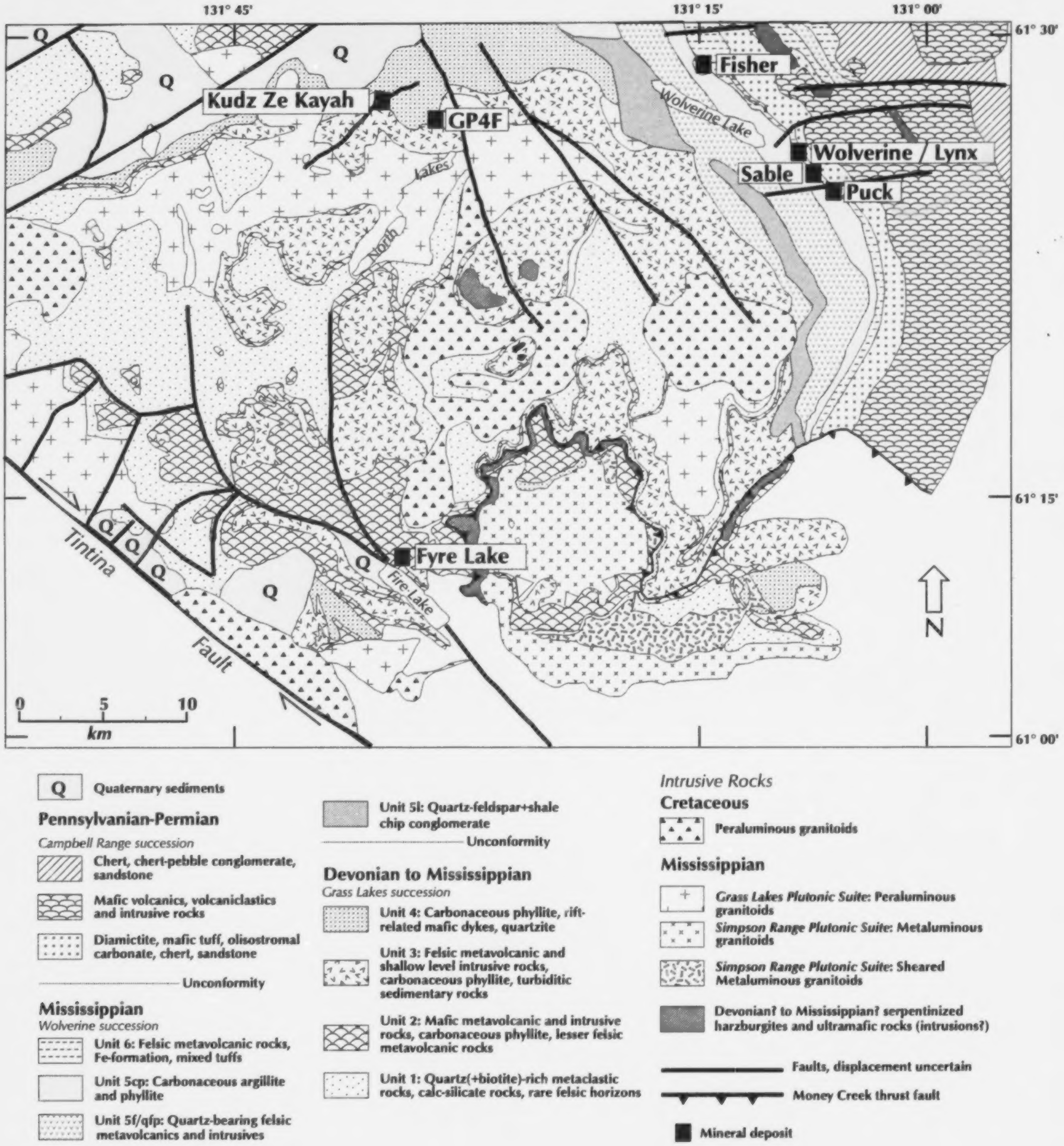
131° 45'
131° 15'
131° 00'
61° 30'
61° 15'
61° 00'
Q
Kudz Ze Kayah
GP4F
Fisher
Wolverine Lake
Wolverine / Lynx
Sable
Puck
North Lakes
Fyre Lake
Fire Lake
Tintina Fault
N
0
5
10
km
Q Quaternary sediments
Pennsylvanian-Permian
Campbell Range succession
Chert, chert-pebble conglomerate, sandstone
Mafic volcanics, volcaniclastics and intrusive rocks
Diamictite, mafic tuff, olisostromal carbonate, chert, sandstone
Unconformity
Mississippian
Wolverine succession
Unit 6: Felsic metavolcanic rocks, Fe-formation, mixed tuffs
Unit 5cp: Carbonaceous argillite and phyllite
Unit 5f/qfp: Quartz-bearing felsic metavolcanics and intrusives
Unit 5l: Quartz-feldspar+shale chip conglomerate
Unconformity
Devonian to Mississippian
Grass Lakes succession
Unit 4: Carbonaceous phyllite, rift-related mafic dykes, quartzite
Unit 3: Felsic metavolcanic and shallow level intrusive rocks, carbonaceous phyllite, turbiditic sedimentary rocks
Unit 2: Mafic metavolcanic and intrusive rocks, carbonaceous phyllite, lesser felsic metavolcanic rocks
Unit 1: Quartz(+biotite)-rich metaclastic rocks, calc-silicate rocks, rare felsic horizons
Intrusive Rocks
Cretaceous
Peraluminous granitoids
Mississippian
Grass Lakes Plutonic Suite: Peraluminous granitoids
Simpson Range Plutonic Suite: Metaluminous granitoids
Simpson Range Plutonic Suite: Sheared Metaluminous granitoids
Devonian? to Mississippian? serpentinized harzburgites and ultramafic rocks (intrusions?)
Faults, displacement uncertain
Money Creek thrust fault
Mineral deposit

Figure 2. *Geological map of the Finlayson Lake region modified from Murphy (1998) and Piercey (1999c) with locations of different zones of the Wolverine VHMS deposit and other VHMS deposits of the Finlayson Lake district.*

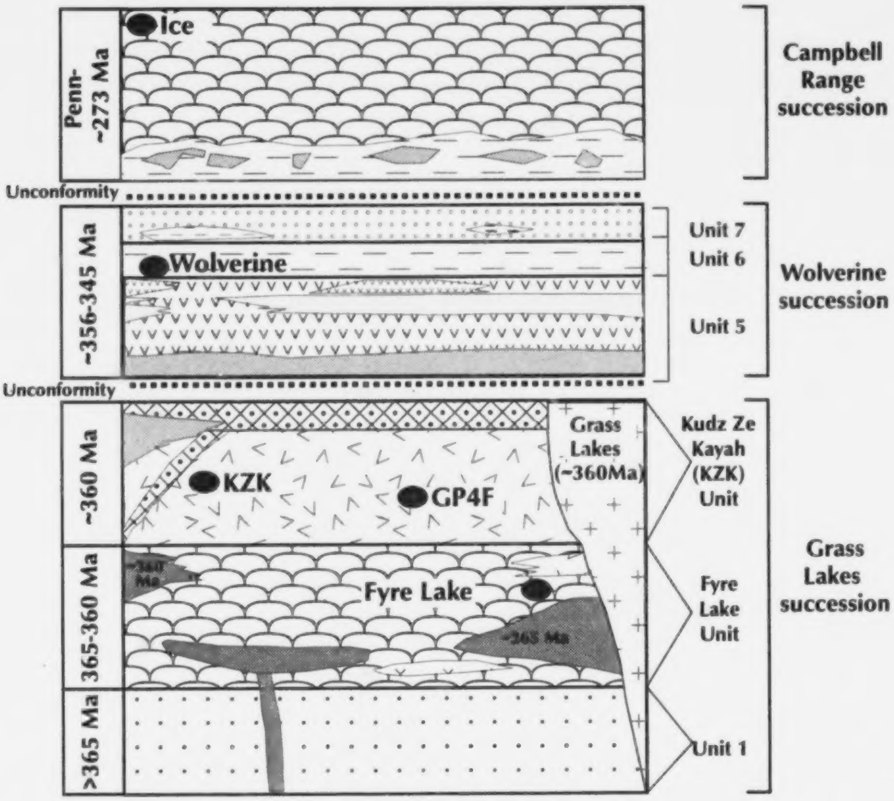
Penn- ~273 Ma
Ice
Campbell Range succession
Unconformity
~356-345 Ma
Wolverine
Unit 7
Unit 6
Unit 5
Wolverine succession
Unconformity
~360 Ma
KZK
GP4F
Grass Lakes (~360Ma)
Kudz Ze Kayah (KZK) Unit
365-360 Ma
~360 Ma
Fyre Lake
~365 Ma
Fyre Lake Unit
>365 Ma
Unit 1
Grass Lakes succession

Figure 3. *Regional stratigraphic column of the host rocks to the VHMS deposits in the Finlayson Lake district (modified after Murphy and Timmerman, 1997; Murphy, 1998; Murphy and Piercey, 1999a,b,c; Piercey and Murphy, 2000).*

between Units 5 and 6 (Fig. 3). The deposit stratigraphy, which is described in the subsequent section, includes the uppermost part of Unit 5, Unit 6, and the lowermost part of Unit 7.

DEPOSIT GEOLOGY

The stratigraphic sequence hosting the deposit will be hereafter referred to as the "Wolverine stratigraphy." The Wolverine stratigraphy is defined in this paper as those rocks 400 m above and 70 m below the massive sulphide mineralization for which there are sufficient data from drill core to establish confidently a coherent stratigraphy that is consistent throughout the entire area of the deposit. The lithologies forming the immediate host-rocks to the deposit are further subdivided below. The surface geology of the Wolverine deposit area is illustrated in Figure 4.

METAMORPHISM AND STRUCTURE

Rocks in the vicinity of the Wolverine deposit have been metamorphosed to middle- or upper-greenschist grade based on a defining metamorphic mineral assemblage of chlorite, actinolite, albite, titanite, carbonate and, in places, biotite. A single major deformational event has obliterated most primary volcanic and sedimentary features in the rocks. This deformational event is recorded as a prominent S_1 foliation, which trends northwest and dips gently to the northeast. This fabric is a curviplanar pressure-solution foliation that is defined by millimetre- to centimetre-scale seams of fine micaceous minerals that display increased spacing in the more siliceous units (e.g., Murphy, 1998).

Folds in the vicinity of the deposit are generally southwest verging, tight, and 'S' shaped when viewed to the northwest along the fold axes. These folds range from drill-core to outcrop scale and likely are related to similarly shaped kilometre-scale folds mapped in the Grass Lakes succession by Murphy (1997). The southwest vergence indicates that the Wolverine deposit is on the western limb of an open, upright, structure (D.C. Murphy, pers. comm., 2000). The relative lack of fold hinges and overturned limbs permits the correlation of units, some only one metre in thickness, between drill holes on the same cross-section (i.e., on the scale of about one half kilometre). Correlation between adjacent drill cores in certain cross-sections indicates some changes in thickness, and/or structural repetition of units near fold hinges. In rare cases, where primary compositional layering is visible, the intersection of the S_1 foliation with bedding (S_0) forms a lineation that parallels the orientation of the fold hinges. The compositional layering and S_1 foliation essentially are parallel except near the vicinity of fold hinges.

Layer-parallel (i.e., parallel to foliation) shearing has resulted in extensive gouge zones in the more ductile rocks (e.g., argillite) and intense fracturing in the more brittle rocks (e.g., rhyolite). Faulting is present to some degree throughout the entire Wolverine stratigraphy, although significant offset (>1 m) has not been identified in the cross-sections. Rootless folds are present locally. Most faults in the Wolverine stratigraphy are attributed to the same major deformational event.

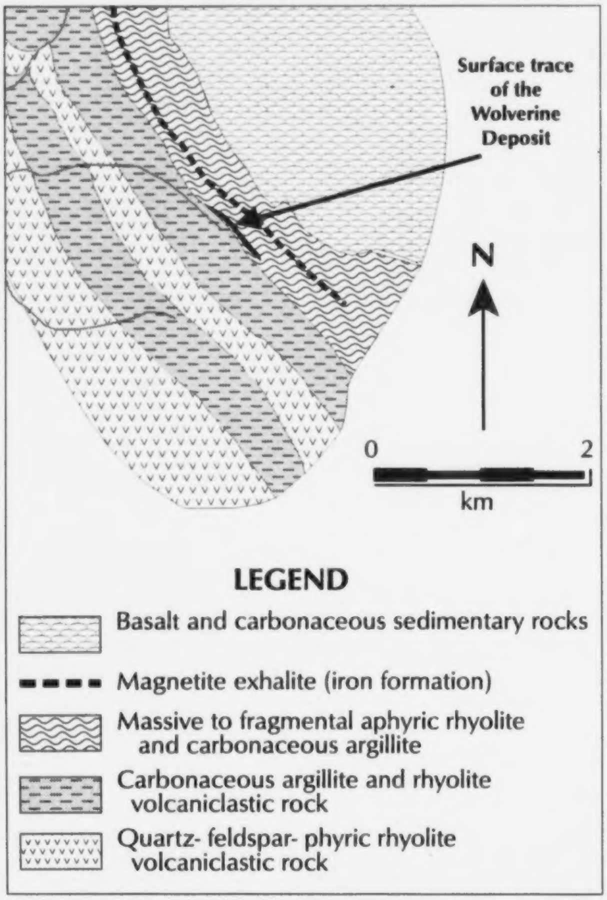
Surface trace
of the
Wolverine
Deposit
N
0
2
km
LEGEND
Basalt and carbonaceous sedimentary rocks
Magnetite exhalite (iron formation)
Massive to fragmental aphyric rhyolite and carbonaceous argillite
Carbonaceous argillite and rhyolite volcaniclastic rock
Quartz- feldspar- phyric rhyolite volcaniclastic rock

Figure 4. *Local geology of the Wolverine deposit (modified from an unpublished map by Expatriate Resources Limited). The arrow points to UTM coordinate 440000E, 6811000N (NAD 27).*

STRATIGRAPHY

Despite greenschist-grade metamorphism and a high degree of deformation, it is possible to recognize volcanic, volcaniclastic and sedimentary protoliths at Wolverine.

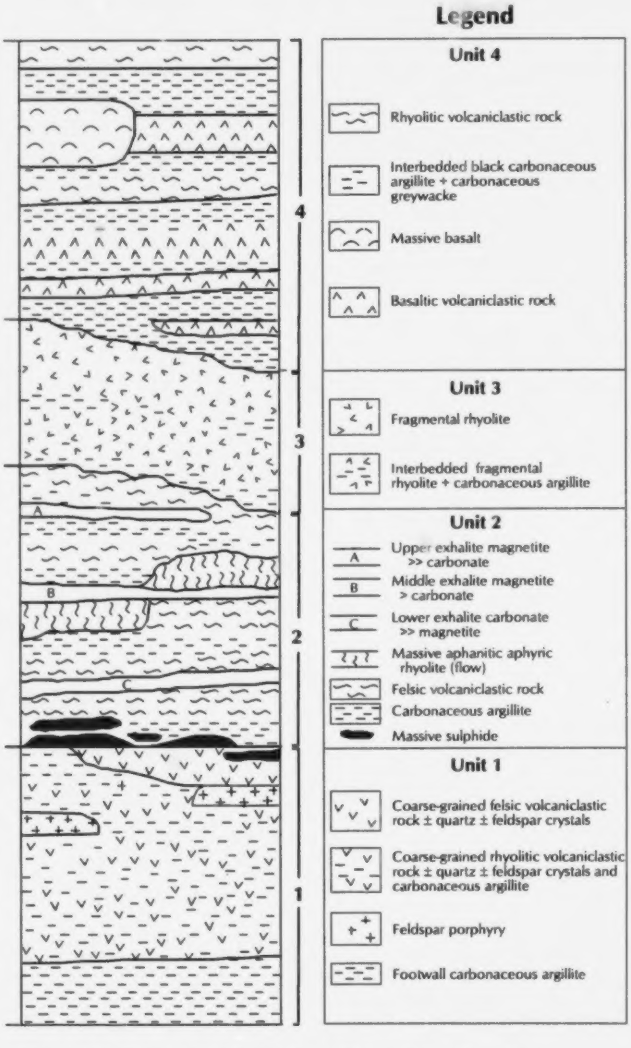
Legend
4
3
2
1
A
B
C
Unit 4
Rhyolitic volcaniclastic rock
Interbedded black carbonaceous argillite + carbonaceous greywacke
Massive basalt
Basaltic volcaniclastic rock
Unit 3
Fragmental rhyolite
Interbedded fragmental rhyolite + carbonaceous argillite
Unit 2
Upper exhalite magnetite >> carbonate
Middle exhalite magnetite > carbonate
Lower exhalite carbonate >> magnetite
Massive aphanitic aphyric rhyolite (flow)
Felsic volcaniclastic rock
Carbonaceous argillite
Massive sulphide
Unit 1
Coarse-grained felsic volcaniclastic rock ± quartz ± feldspar crystals
Coarse-grained rhyolitic volcaniclastic rock ± quartz ± feldspar crystals and carbonaceous argillite
Feldspar porphyry
Footwall carbonaceous argillite

Figure 5. *Generalized stratigraphic column for the Wolverine deposit. Constructed from detailed geological mapping of drill core, drill logs, and cross-sections supplied by Expatriate Resources Limited.*

In this paper, the Wolverine stratigraphy has been divided into four successive units, each of which consists of several different lithologies. The units are described below (from oldest to youngest) and illustrated in Figures 5, 6, 7 and 8a-d. Importantly, exhalative lithologies, which include massive sulphides, are restricted to Unit 2. The Wolverine stratigraphy appears to be upright and not overturned, such as at the Kudz Ze Kayah deposit (e.g., Schultze, 1996).

Unit 1 - Footwall Volcaniclastic, Carbonaceous Sedimentary and Porphyritic Intrusive Rocks

(1) *Green to grey quartz- and feldspar-crystal-bearing rhyolite volcaniclastic rock with variable amounts of interbedded carbonaceous argillite.* Flattened, fine- to coarse-grained fragments of rhyolite are abundant in this lithology, which also contains up to several volume percent (vol. %) K-feldspar and quartz crystals although either, or both, may be absent. Potassium feldspar crystals are subhedral to euhedral in shape and range from 1 to 5 mm in diameter, whereas similarly sized greyish-blue quartz 'eyes' have rounded outlines. The relative abundances of feldspar crystals, quartz eyes and rhyolite fragments in this lithology vary significantly throughout the deposit.

(2) *Black to grey, fine-grained, carbonaceous, tuffaceous argillite.* This rock commonly contains several vol. % grey tuff as layers or clasts, and up to several vol. % rounded blue quartz eyes ranging up to 1 mm in diameter. This footwall argillite is similar to the

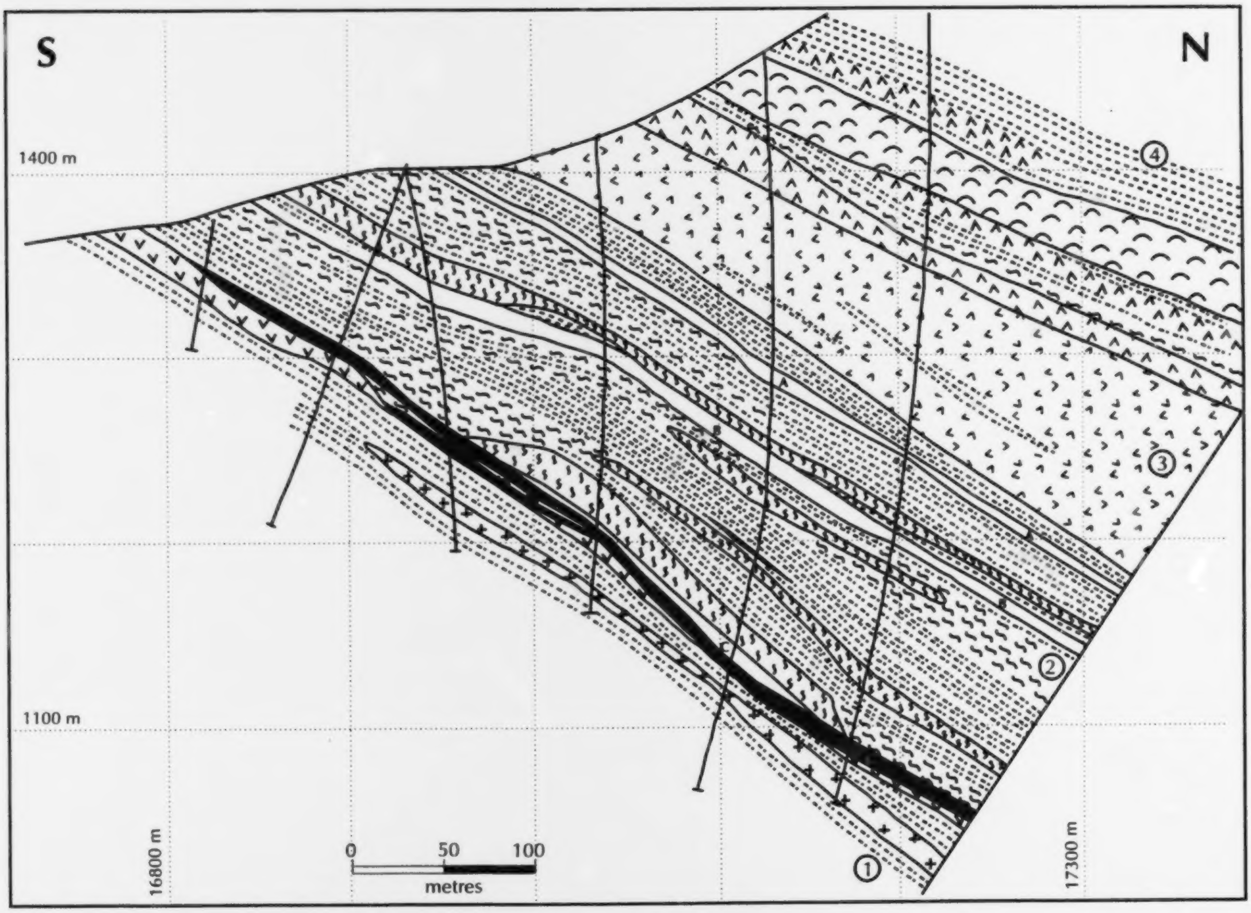

Figure 6. *Geological cross-section 16250E through the Lynx zone of the Wolverine deposit. The location of this cross-section is shown on Figure 9. Constructed from detailed geological mapping of drill core, drill logs and cross-sections supplied by Expatriate Resources Limited. Coordinates (in metres) are from the property grid (Fig. 9). Unit numbers and patterns shown in Figure 5.*

carbonaceous argillite in the hanging wall but is locally distinguished by a slightly coarser grain size, lighter colour, and the presence of quartz eyes in the former.

(3) *Grey, weakly foliated, K-feldspar-phyric rhyolite porphyry* (Fig. 8a). This intrusive lithology contains 5 to 10 vol. % K-feldspar phenocrysts up to 5 to 10 mm in diameter, in a grey, aphanitic, siliceous groundmass. Grey quartz-eyes are rare.

The massive sulphide lens typically lies immediately above or, in some areas, within the felsic volcaniclastic rocks, which range from 1 to 60 m in width. The 30- to 50-m-thick carbonaceous argillite in the footwall marks the base of the volcano-sedimentary sequence, which hosts the mineralization. The 6- to 15-m-thick K-feldspar-phyric porphyries occur at an average distance of 20 m below the base of the massive sulphide horizon and are interpreted to be intrusive sills. The porphyry contains sulphide veins in at least one drill hole, which suggests emplacement was prior to mineralization. Piercey et al. (2001, this volume) describe the nature and occurrence of this lithology in more detail.

Unit 2 – Interbedded Argillite, Rhyolite and Magnetite-Carbonate-Pyrite Exhalites

(1) *Grey, massive to flow-banded, aphanitic to very fine-grained, aphyric rhyolite.* This rock is composed of alternating domains of aphanitic rhyolite with sub-millimetre to centimetre-thick micaceous partings

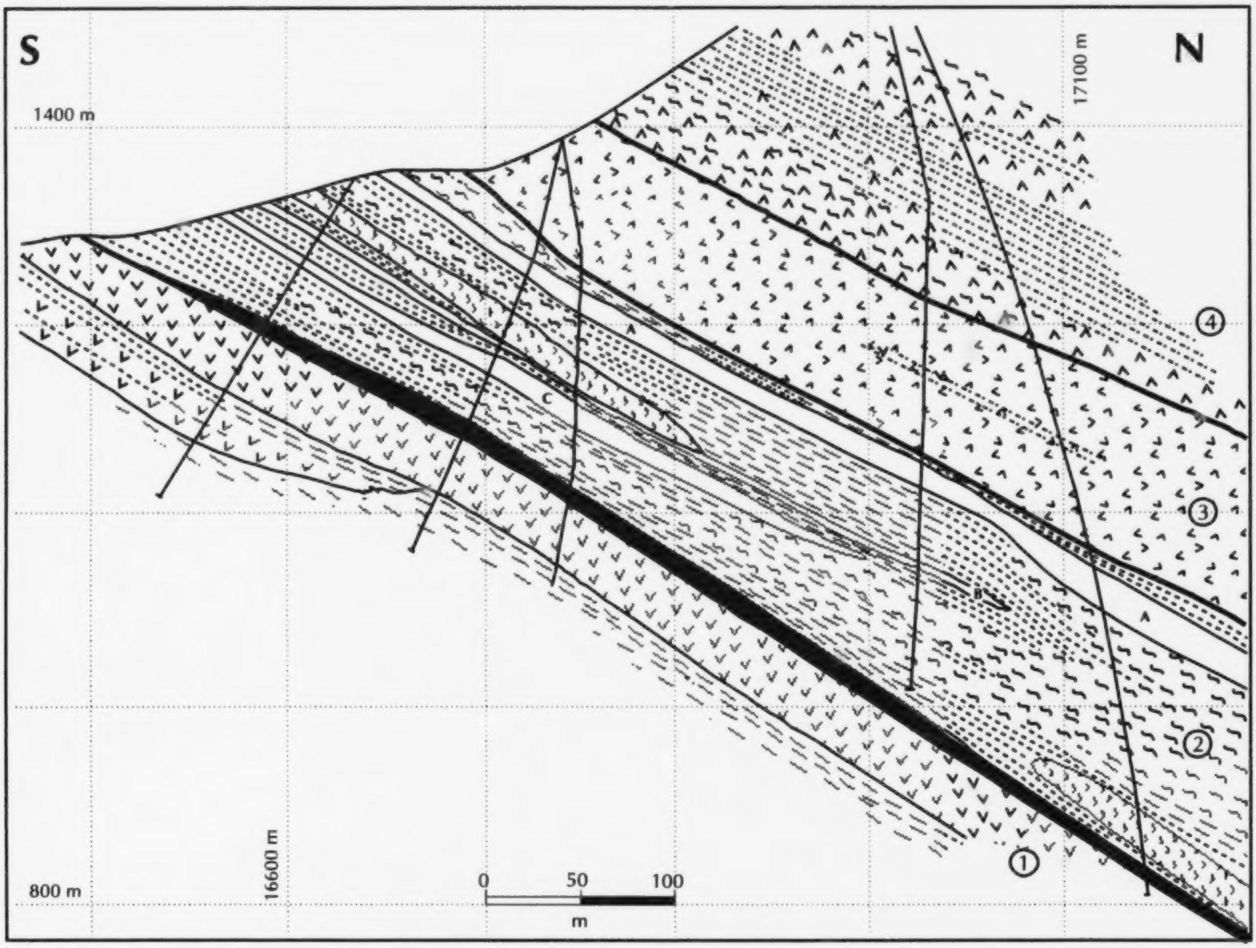

Figure 7. *Geological cross-section 16700E through the Wolverine zone of the Wolverine deposit. The location of this cross-section is shown on Figure 9. Constructed from detailed geologic mapping of drill core, drill logs and cross-sections supplied by Expatriate Resources Limited. Coordinates (in metres) are from the property grid (Fig. 9). Unit numbers and patterns shown in Figure 5.*

oriented parallel to the dominant S_1 foliation. The rhyolite domains commonly contain minute K-feldspar (?) microlites.

(2) *Black, finely laminated, carbonaceous argillite.* This rock commonly contains several vol. % grey tuff layers or clasts. A strongly siliceous variant contains abundant flattened and sheared veins of quartz and pyrite.

(3) *Grey to black, magnetite-predominant exhalite (iron formation;* Fig. 8b). This rock contains 5 to 60 vol. % disseminated to massive layered magnetite with lesser carbonate, chlorite, quartz, and sericite. The layering is interpreted to be a primary feature and where present, commonly assumes the form of millimetre-scale monomineralic bands of magnetite interbedded with layers of mixed silicates and carbonates.

(4) *Grey to white, carbonate-predominant exhalite* (Fig. 8c). This exhalite contains up to 90 vol. % patchy to massive fine carbonate (calcite > ankerite > siderite) with lesser magnetite, chlorite and pyrite. These rocks only rarely exhibit fine laminations; field relations suggest that the layers have responded in a ductile manner to deformation and primary sedimentary textures are now transposed.

(5) *Fine-grained, polymetallic, massive sulphides.* The types and styles of mineralization present in Unit 2 are described separately in the following section.

The immediate host-rock sequence to the massive sulphide mineralization ranges from 85 to 160 m in thickness and includes four distinct exhalative lithologies (not all of which are present in each drill hole). The uppermost two are commonly magnetite-predominant exhalite (A and B), the middle is a carbonate-predominant exhalite (C), and the lowermost is a pyrite-predominant exhalite (massive sulphide; see Figs. 5 and 7). The

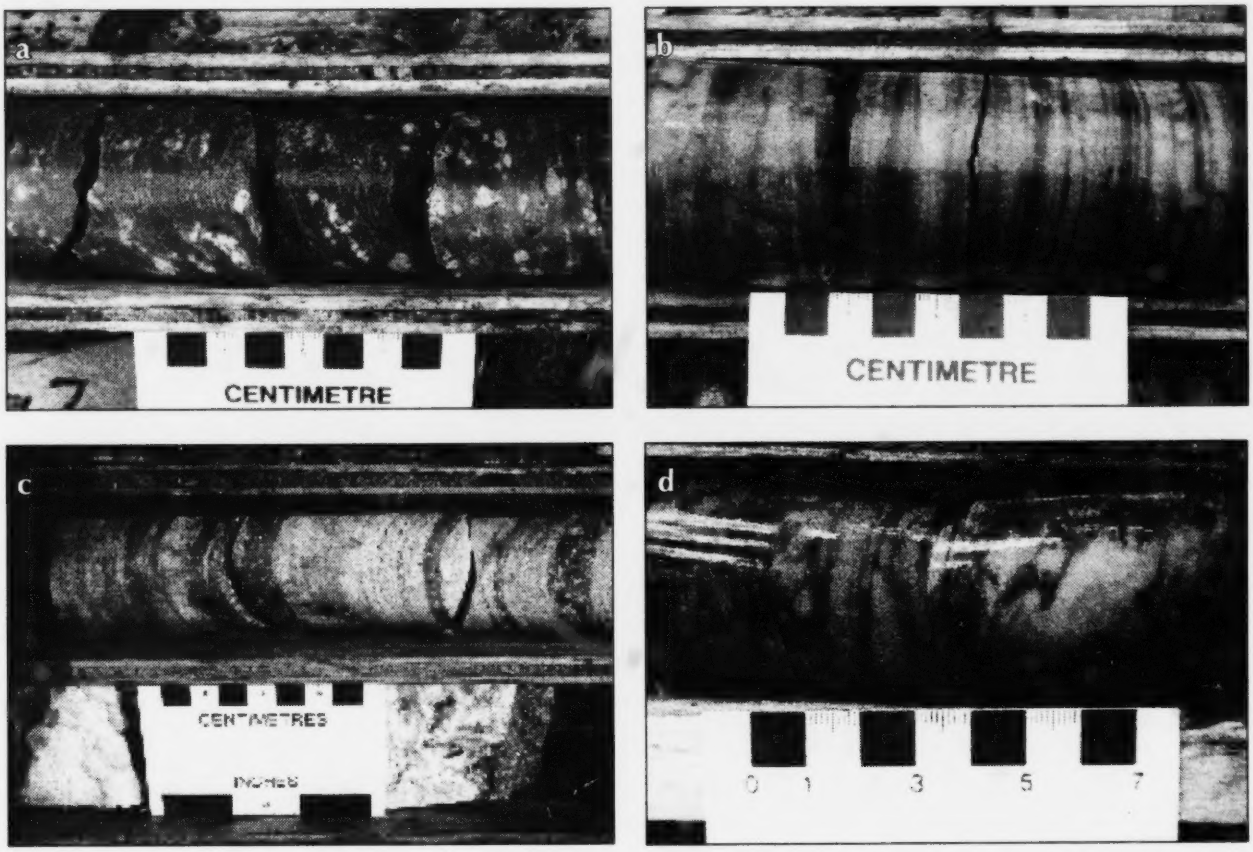

Figure 8. *Photographs of host-rock lithologies: (a) K-feldspar–phyric rhyolite porphyry of Unit 1; (b) magnetite exhalite (iron formation) of Unit 2; (c) carbonate-pyrite exhalite of Unit 2; and (d) fragmental rhyolite of Unit 3.*

thickness of the individual exhalites ranges from less than 1 m up to 10 m. The magnetite-rich exhalites are laterally extensive with strike lengths in excess of 12 km. All exhalites are separated by mixed sequences of interbedded argillite and rhyolite, which are commonly interbedded on the scale of a centimetre. The thickness of individual rhyolite and argillite horizons is extremely variable at the scale of the deposit. Both massive rhyolite and carbonaceous argillite may attain widths of up to 30 m. Some massive rhyolite intervals have a fine-grained base, which grades upward into feldspar-microlite-bearing rhyolite and subsequently into a rhyolite breccia (a flow-top breccia?). Collectively, these features suggest emplacement as flows.

Unit 3 – Fragmental Rhyolite

(1) *Grey fragmental rhyolite* (Fig. 8d). This rock is characterized by wispy, sub-millimetre, dark green to black, anastomosing micaceous bands, which separate centimetre-sized felsic aphanitic volcanic rock fragments. These fragments are sub-angular to sub-rounded, irregularly shaped and possess ragged boundaries. A variant of this unit has a distinctive greenish hue and contains 1 to 2 vol. % disseminated magnetite, which may be a product of weak semi-conformable (?) chloritic alteration.

(2) *Grey to black fragmental rhyolite and black carbonaceous argillite.* Rhyolite fragments (50 to 90 vol. %) are generally centimetre-sized, ovoid, and flattened into the plane of foliation. This lithology is similar to the fragmental rhyolite described above but may be distinguished from it by its greater proportion of argillite.

This unit occurs above the mineralized sequence and its base is marked generally by the presence of the uppermost exhalite. The thickness of this unit is fairly constant throughout the deposit, averaging about 80 m.

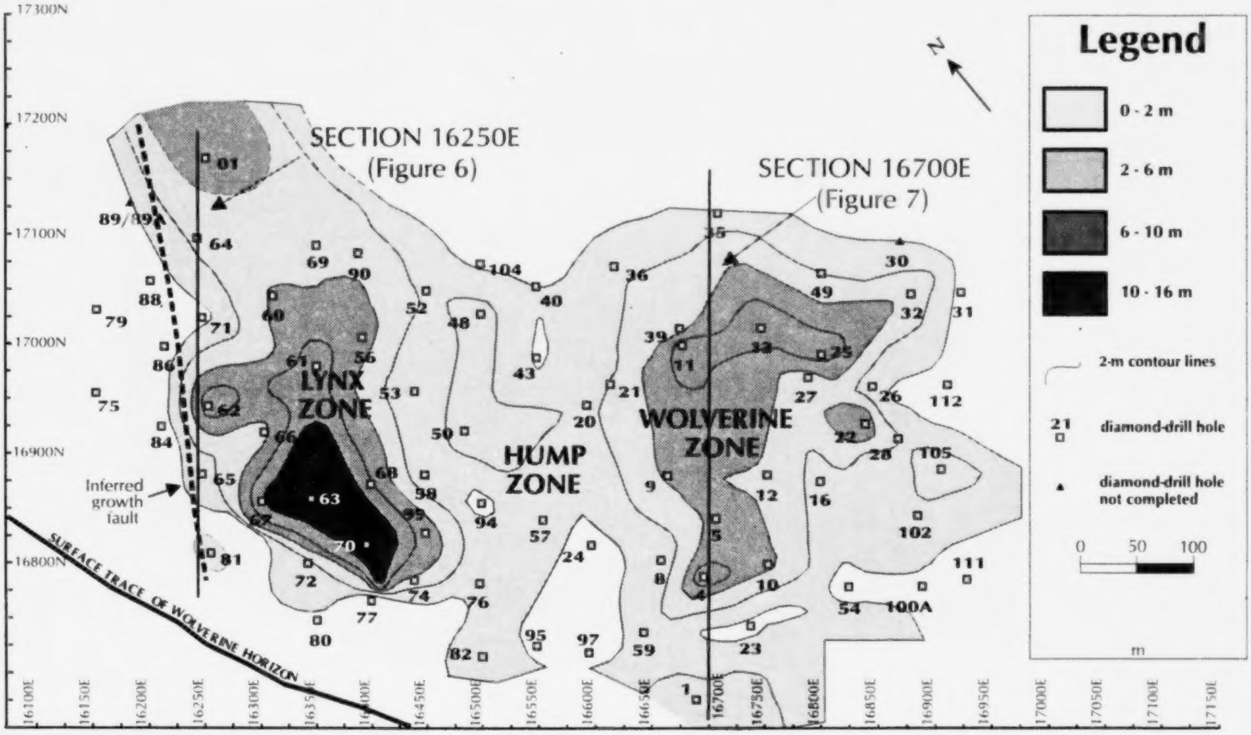
17300N
17200N
17100N
17000N
16900N
16800N
SECTION 16250E
(Figure 6)
SECTION 16700E
(Figure 7)
N
LYNX ZONE
HUMP ZONE
WOLVERINE ZONE
Inferred growth fault
SURFACE TRACE OF WOLVERINE HORIZON
01 89/89A 64 69 90 104 40 36 35 30 49 32 31 88 79 71 60 52 48 39 33 25 11 86 61 56 43 21 27 26 112 75 62 53 20 84 66 50 22 28 105 65 68 58 9 12 16 63 94 57 102 67 95 5 111 81 70 24 8 10 72 74 76 54 100A 77 80 95 97 59 23 82 1
16100E 16150E 16200E 16250E 16300E 16350E 16400E 16450E 16500E 16550E 16600E 16650E 16700E 16750E 16800E 16850E 16900E 16950E 17000E 17050E 17100E 17150E
Legend
0 - 2 m
2 - 6 m
6 - 10 m
10 - 16 m
2-m contour lines
21 diamond-drill hole
diamond-drill hole not completed
0 50 100
m

Figure 9. *Contours of true thickness of massive sulphide mineralization projected to the surface. Figure illustrates the morphology of sulphide mineralization associated with the Wolverine, Lynx, and Hump zones. The locations of the individual drill holes are projected to the base of the massive sulphide intersection. Coordinates (in metres) are from the property grid. Modified from Expatriate Resources Limited (2000). Property grid shown – grid number 16900N, 16650E equals approximately 440000E, 6811000N (UTM coordinates, NAD 27).*

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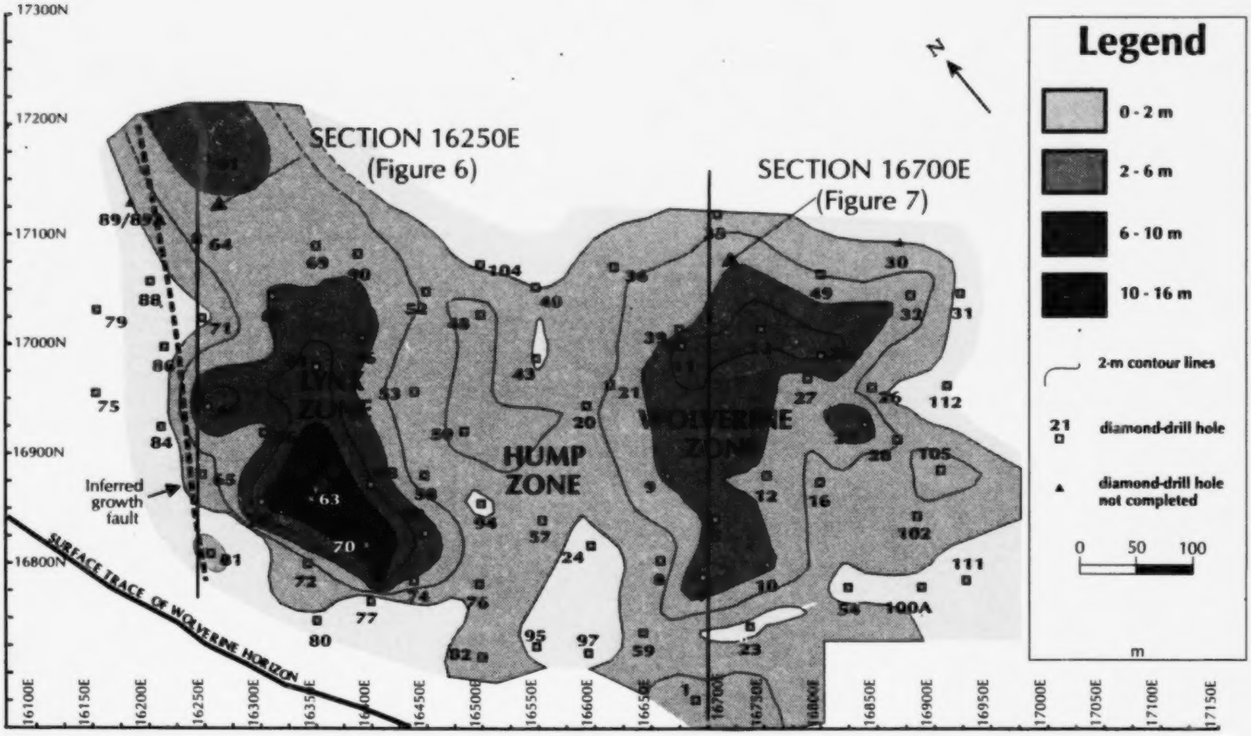
17300N
17200N
17100N
17000N
16900N
16800N
SECTION 16250E
(Figure 6)
SECTION 16700E
(Figure 7)
N
LYNX ZONE
HUMP ZONE
WOLVERINE ZONE
Inferred growth fault
SURFACE TRACE OF WOLVERINE HORIZON
89/89A
64
65
90
104
40
36
35
30
49
32
31
88
79
71
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48
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112
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111
81
72
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76
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80
95
97
59
02
10
58
100A
23
1
16100E
16150E
16200E
16250E
16300E
16350E
16400E
16450E
16500E
16550E
16600E
16650E
16700E
16750E
16800E
16850E
16900E
16950E
17000E
17050E
17100E
17150E
Legend
0 - 2 m
2 - 6 m
6 - 10 m
10 - 16 m
2-m contour lines
21 diamond-drill hole
diamond-drill hole not completed
0
50
100
m

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Unit 4 – Interbedded Carbonaceous Argillite and Greywacke, with lesser Basalt and Rhyolite

(1) *Medium-green, massive, fine-grained basalt with biotite and minor epidote on partings.* These rocks are interpreted as flows where massive and homogeneous. They are likely volcaniclastic in origin where interbedded and layered with carbonaceous sedimentary rocks.

(2) *Interbedded black carbonaceous argillite and grey to black, medium-grained greywacke.* These rocks contain minor beds of felsic volcaniclastic rocks that are similar in appearance to the fragmental rhyolite of Unit 3 described above.

This uppermost sequence probably represents the transition from the Wolverine stratigraphy to the overlying basaltic flows and volcaniclastic rocks of the Campbell Range succession. The upper limit to this unit is unknown, but its thickness is at least 200 m. The basalts and the carbonaceous sedimentary rocks are mostly interbedded on a centimetre scale, although individual massive basalt (flows?) and carbonaceous sedimentary sequences can reach up to 40 m and 30 m in thickness, respectively. The base of this unit is defined by the first occurrence of green basaltic volcaniclastic rock.

MINERALIZATION

Massive sulphide mineralization occurs most commonly at or near the contact between units 1 and 2, where the transition from interbedded, massive, aphyric rhyolite and carbonaceous argillite to more coarsely grained and quartz- and K-feldspar-phyric rhyolitic volcaniclastic rock is located. The immediate hanging wall to the massive

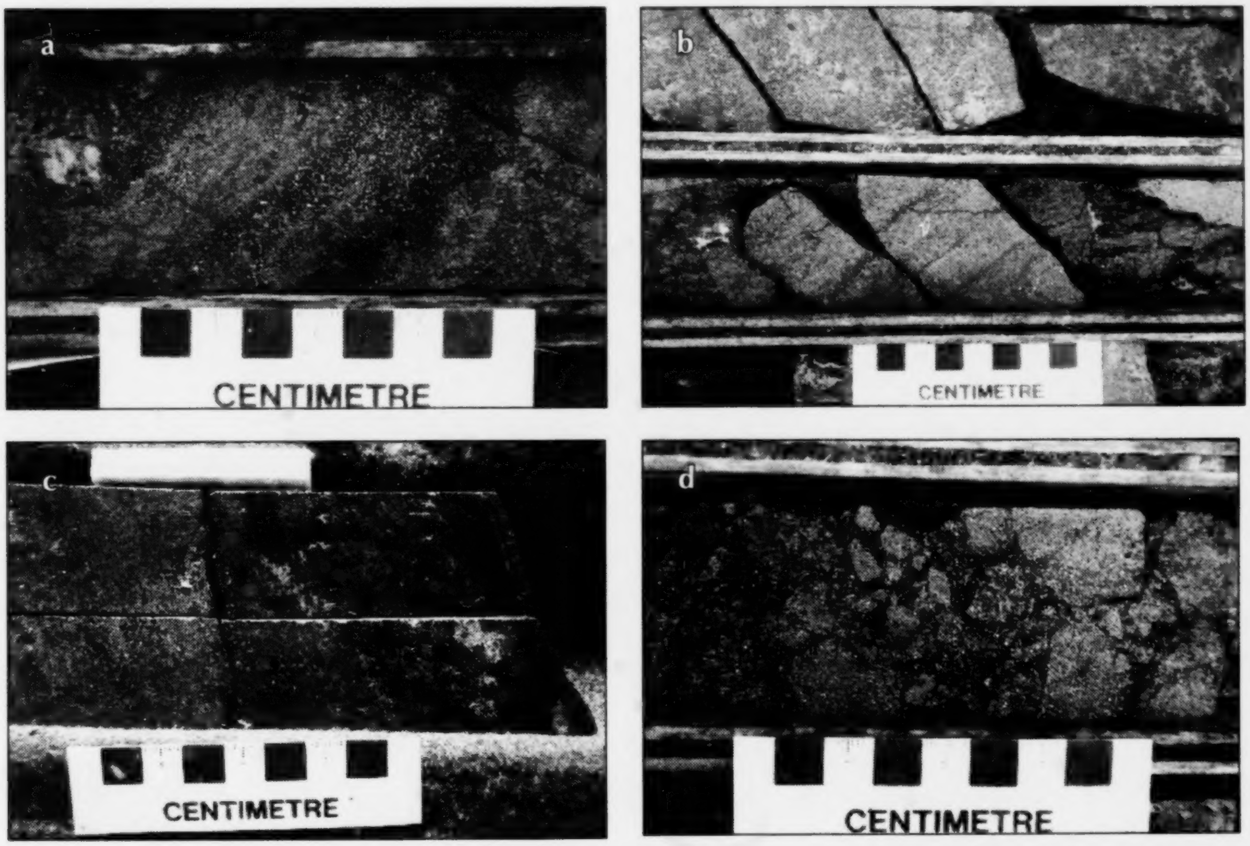


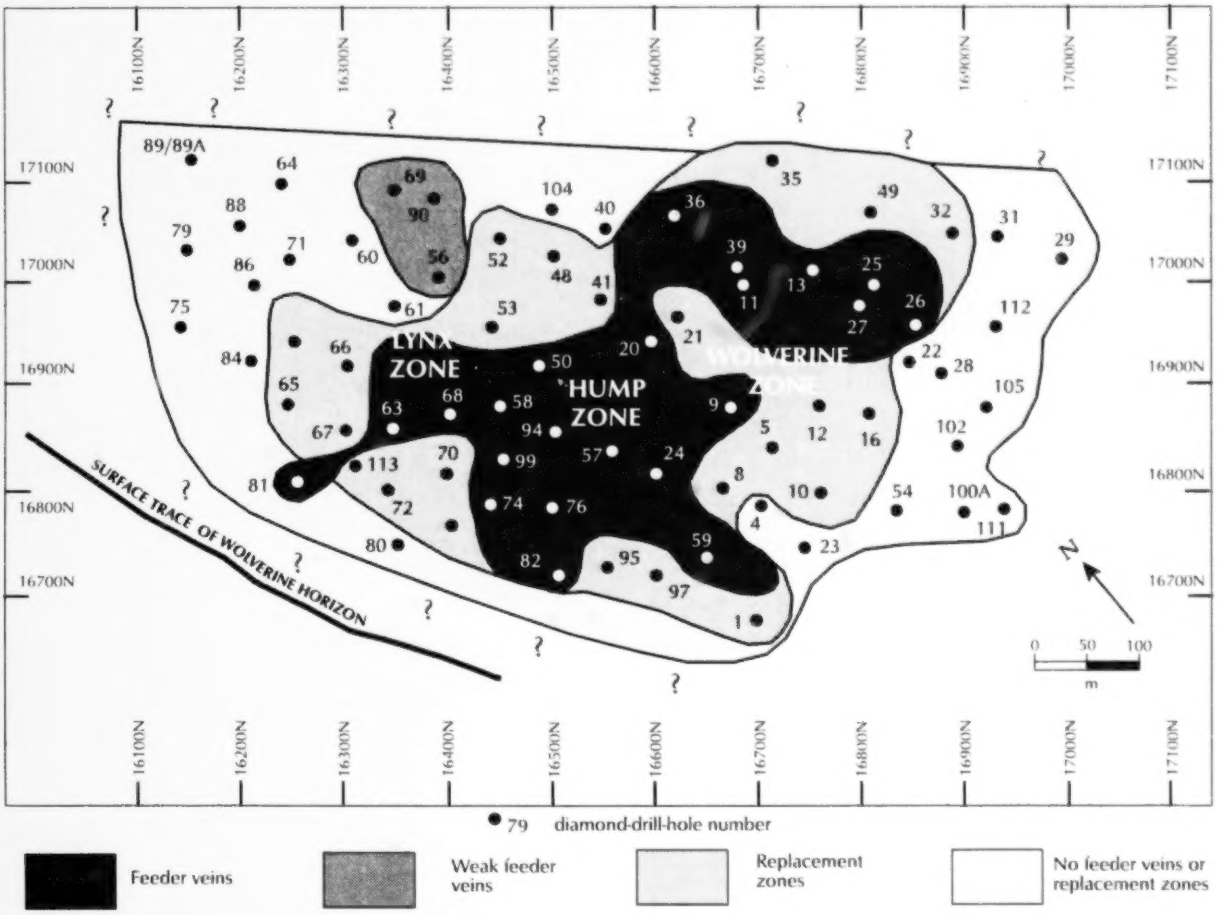
Figure 10. *Photographs of massive sulphide mineralization: (a) layered, massive pyrite and sphalerite, with lesser disseminated euhedral 'buckshot' pyrite; (b) large, angular, breccia fragment composed of layered (possibly laminated) pyrite and sphalerite; (c) pyrrhotite-chalcopyrite-chlorite altered/replaced rhyolite at the base of the massive sulphide intersection; and (d) sulphide breccia with angular to subrounded fragments of pyrite set in a medium-grained pyrite matrix.*

sulphide mineralization is typically black, graphitic argillite of unit 2.

On the basis of style and mineralogy, the sulphide mineralization at Wolverine has been divided into three predominant types: (1) massive stratiform, (2) semi-massive replacement, and (3) sulphide stringer veins. Examples of these rocks are shown in Figure 10. The distribution of the mineralization is illustrated in Figure 9, which contours the surface projection of the true thickness of the massive sulphide intersection in each drill hole. The true widths of the sulphide mineralization shown in Figure 9 represent a combination of massive stratiform (including multiple lenses if present), semi-massive replacement, and sulphide stringer veins.

(1) MASSIVE STRATIFORM SULPHIDES

Most of the mineralization occurs in tabular, homogeneous massive sulphide lenses composed of pyrite and sphalerite with lesser amounts of pyrrhotite, chalcopyrite, galena, tetrahedrite-tennantite and arsenopyrite. Other trace minerals identified in previous studies include marcasite, native gold and native silver (Expatriate Resources, unpublished data, 1996). Meneghinite ($Pb_{13}CuSb_7S_{13}$) is the predominant lead sulfosalt mineral. It is distributed locally together with lesser bournonite ($PbCuSbS_3$), boulangerite ($Pb_5Sb_4S_{11}$), and miargyrite ($Ag_2SSb_2S_3$; Expatriate Resources, unpublished data, 1996). Common gangue minerals are quartz, calcite, dolomite, ankerite, siderite, chlorite and


16100N
16200N
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16900N
17000N
17100N
LYNX ZONE
HUMP ZONE
WOLVERINE ZONE
SURFACE TRACE OF WOLVERINE HORIZON
N
0
50
100
m
89/89A
?
● 79 diamond-drill-hole number
Feeder veins
Weak feeder veins
Replacement zones
No feeder veins or replacement zones

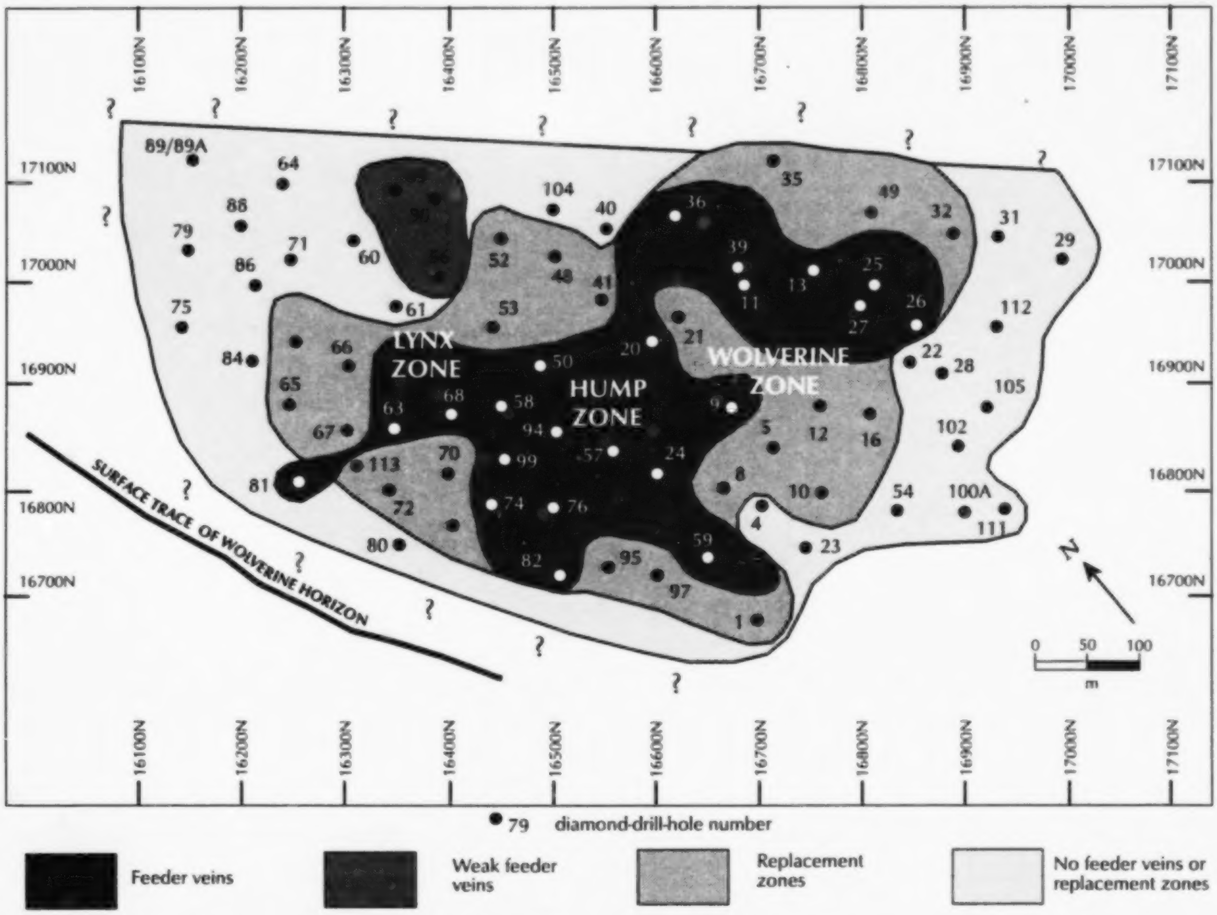
Figure 11. Plan map of the Wolverine deposit showing the distribution of stringer veins ('feeder veins') and replacement-style mineralization. The locations of the individual drill-holes are projected to the base of the massive sulphide intersection. Coordinates (in metres) are from the property grid (J. Peter and S. Paradis, unpublished data, 2000). See Figure 9 for UTM coordinates of property grid.

sulphide mineralization is typically black, graphitic argillite of unit 2.

On the basis of style and mineralogy, the sulphide mineralization at Wolverine has been divided into three predominant types: (1) massive stratiform, (2) semi-massive replacement, and (3) sulphide stringer veins. Examples of these rocks are shown in Figure 10. The distribution of the mineralization is illustrated in Figure 9, which contours the surface projection of the true thickness of the massive sulphide intersection in each drill hole. The true widths of the sulphide mineralization shown in Figure 9 represent a combination of massive stratiform (including multiple lenses if present), semi-massive replacement, and sulphide stringer veins.

(1) MASSIVE STRATIFORM SULPHIDES

Most of the mineralization occurs in tabular, homogeneous massive sulphide lenses composed of pyrite and sphalerite with lesser amounts of pyrrhotite, chalcopyrite, galena, tetrahedrite-tennantite and arsenopyrite. Other trace minerals identified in previous studies include marcasite, native gold and native silver (Expatriate Resources, unpublished data, 1996). Meneghinite ($Pb_{13}CuSb_7S_{13}$) is the predominant lead sulfosalt mineral. It is distributed locally together with lesser bournonite ($PbCuSbS_3$), boulangerite ($Pb_5Sb_4S_{11}$), and miargyrite ($Ag_2SSb_2S_3$; Expatriate Resources, unpublished data, 1996). Common gangue minerals are quartz, calcite, dolomite, ankerite, siderite, chlorite and


16100N
16200N
16300N
16400N
16500N
16600N
16700N
16800N
16900N
17000N
17100N
17100N
17000N
16900N
16800N
16700N
LYNX ZONE
HUMP ZONE
WOLVERINE ZONE
SURFACE TRACE OF WOLVERINE HORIZON
89/89A
64
88
79
71
60
86
75
84
66
65
67
63
68
90
56
52
48
61
53
104
40
41
50
58
94
20
21
36
35
39
13
11
25
27
26
49
32
31
29
112
22
28
105
102
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99
113
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m
79 diamond-drill-hole number
Feeder veins
Weak feeder veins
Replacement zones
No feeder veins or replacement zones

Figure 11. Plan map of the Wolverine deposit showing the distribution of stringer veins ('feeder veins') and replacement-style mineralization. The locations of the individual drill-holes are projected to the base of the massive sulphide intersection. Coordinates (in metres) are from the property grid (J. Peter and S. Paradis, unpublished data, 2000). See Figure 9 for UTM coordinates of property grid.

sericite. These minerals occur interstitial to the sulphide minerals and commonly form either very fine-grained masses or irregular blebs. Gangue minerals typically comprise less than 5 vol. % of the mineralized zones.

The two 'lens-like' areas where the accumulation of massive sulphides is thickest are termed the Wolverine zone and the Lynx zone (Fig. 9). These zones are separated from one another by an area of non-stratiform, semi-massive replacement sulphide mineralization and sulphide-stringer vein mineralization, which occurs at or near the same stratigraphic horizon as the massive sulphide lenses. This area is termed the Hump zone.

The sulphide lenses range in thickness from less than 1 m near the fringes of the deposit to 9.8 m in the Wolverine zone. In some localities, such as in the thickest sections of the Lynx zone, there are multiple sulphide lenses separated by up to 8 m of argillite or rhyolite. These multiple lenses may represent distinct exhalative horizons (i.e., stacked sulphide lenses), or may be the result of structural repetition due to folding or structural dismemberment. Examples of the stratiform massive sulphide mineralization, and the different textures they exhibit, are discussed below and shown in Figures 10a-d.

(2) SEMI-MASSIVE REPLACEMENT SULPHIDES

Figure 11 is a plan view of the deposit illustrating the distribution of the sulphide stringer vein and semi-massive replacement-type sulphide mineralization. Replacement zones are those areas of mineralization where sulphide minerals have partly to completely replaced host rocks. This has resulted in discrete, fine-grained, semi-massive sulphide zones ranging in thickness from several centimetres up to one metre. Replacement-type mineralization is most common in the Hump zone, but it also forms in the immediate footwall to the stratiform massive sulphide lenses in the Wolverine and Lynx zones. Here, it is associated with strongly chloritized and/or carbonatized rhyolite and argillite.

Replacement-type mineralization generally surrounds and occurs above and outboard of the stringer vein mineralization. Sphalerite is the most common replacement sulphide mineral and it occurs as either massive layers or irregular blebs and disseminations together with subordinate pyrite. Semi-massive pyrite and sphalerite replacement-type mineralization hosted by chloritized and carbonatized rhyolite and argillite in the Hump zone reaches up to 13 m in thickness. Semi-massive pyrite and sphalerite replacement-type mineralization in the footwall of the stratiform massive sulphide in the Wolverine zone ranges from 6 to 8 m in thickness. Chalcopyrite commonly forms small, semi-massive replacement zones in the immediate footwall to the sphalerite-rich massive stratiform sulphide mineralization. Chalcopyrite replacement zones typically have well defined upper and lower boundaries, are on the order of 30 cm thick, contain 60 to 80 vol. % massive to interstitial chalcopyrite with minor pyrrhotite, and are associated with intense and pervasive chloritic alteration of the host rocks.

(3) SULPHIDE STRINGER VEINS

Sulphide stringer vein zones are strongly developed in several areas of the deposit. Stringer vein mineralization is developed most strongly beneath, and intermixed with, massive replacement-type sulphide mineralization in the Hump zone. It is also prevalent in the immediate footwall to the thickest stratiform, and semi-massive replacement-style mineralization in the Wolverine zone. Well mineralized zones of this type comprise 5 to 10 vol. % of the rock and consist of randomly oriented, 2- to 3-cm-wide veins of quartz, pyrite and sphalerite. An envelope of silicification commonly surrounds individual veins. These areas of strong vein development are interpreted as up-flow conduits or pathways for hydrothermal fluids that precipitated the overlying massive stratiform sulphide mineralization. Thus, sulphide stringer veins are tentatively identified as the 'feeder zones' to massive sulphide mineralization. Where well developed, such as in the Wolverine zone, stringer vein mineralization ranges in thickness from 1 to 4 m. Weakly developed stringer vein mineralization is much more widespread, however, and it consists of 5- to 10-mm-wide quartz-sulphide veins that lack significant alteration envelopes. In the Wolverine zone, weakly developed quartz-chalcopyrite stringer veins extend approximately 10 m into the chloritized footwall.

SULPHIDE TEXTURES

Stratiform sulphide lenses are generally fine grained and homogeneous, although millimetre- to centimetre-scale layering is locally common. Pyrite is the principal sulphide mineral throughout the deposit and it typically occurs as very fine-grained, anhedral masses. Pyrite also forms more coarsely grained porphyroblasts (termed 'buckshot' pyrite), which are set in a matrix of finer grained pyrite and/or sphalerite (Fig. 10a). Abundant, fine-grained, reddish brown (i.e., iron-rich) sphalerite forms delicate, wispy, sub-millimetre- to centimetre-scale layers. These layers are largely responsible for the bedded appearance of the massive sulphide mineralization (Fig. 10b). In most places, layers are parallel to the S_1 foliation and are likely a result of deformation, although there are primary sedimentary features preserved in places. Some sphalerite also occurs as very small grains interstitial to massive pyrite.

Galena, tetrahedrite-tennantite, and arsenopyrite are all common sulphide minerals in the massive sulphide lenses, although they are difficult to distinguish from one another in hand specimen. They typically occur together as fine-grained, anhedral aggregates within sphalerite-rich layers. Tetrahedrite-tennantite also occurs as very fine grains interstitial to pyrite, although this is difficult to identify due to the fine-grained nature of the mineralization. Chalcopyrite is rare within the stratiform sulphide lenses. It occurs almost exclusively as remobilized medium-grained masses on the edges of large patches of quartz gangue or wall-rock fragments (Fig. 10c).

Breccia textures are preserved on the eastern flank of the Lynx zone, where they occur both at the top of the massive sulphide lens and within it. Breccias are composed entirely of sulphide minerals and are classified into two types: (1) matrix-supported breccia with 3- to 5-mm-diameter rounded clasts of fine-grained pyrite set in a matrix of similarly fine-grained pyrite comprising 20 to 30 vol. % of the rock; and (2) clast-supported 'jigsaw' breccia with angular clasts of pyrite and sphalerite, ranging from one up to several centimetres in diameter, set in a pyrite matrix comprising 5 to 20 vol. % of the rock (Fig. 10d). Both types of breccia are interpreted as primary features associated with the formation of the massive sulphide on the sea floor. Their nature and distribution are the subject of further investigation.

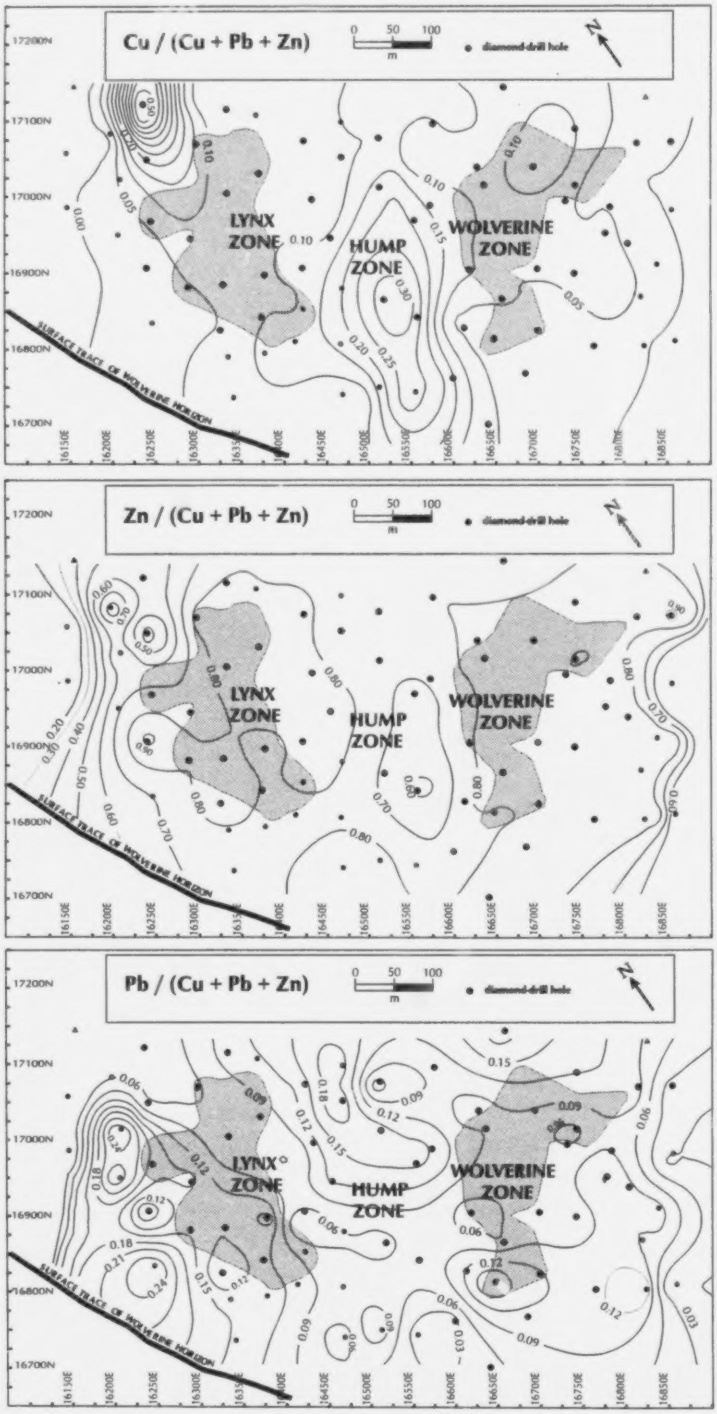
Cu / (Cu + Pb + Zn)
Zn / (Cu + Pb + Zn)
Pb / (Cu + Pb + Zn)
0 50 100
m
• diamond-drill hole
N
LYNX ZONE
HUMP ZONE
WOLVERINE ZONE
SURFACE TRACE OF WOLVERINE HORIZON
17200N
17100N
17000N
16900N
16800N
16700N
16150E
16200E
16250E
16300E
16350E
16400E
16450E
16500E
16550E
16600E
16650E
16700E
16750E
16800E
16850E

Figure 12. *Contours of (a) Cu / Cu + Pb + Zn, (b) Zn / Cu + Pb + Zn, and (c) Pb / Cu + Pb + Zn that illustrate the lateral zonation of copper, lead, and zinc in the Wolverine deposit. Note the correspondence of elevated copper values to the location of the Hump zone. The positions of the individual drill-holes are projected to the base of the massive sulphide intersection. Plots are generated from data provided by Expatriate Resources Limited. See Figure 9 for UTM coordinates of property grid.*

MINERAL AND METAL ZONATION

Figures 12a-c illustrate the lateral zoning of copper, zinc, and lead, respectively. The combined metal grades used to generate the contours represent, in most cases, a combination of massive stratiform mineralization and semi-massive replacement/sulphide stringer vein mineralization (where the latter has significant grade). The distribution of copper (Fig. 12a) is controlled by chalcopyrite, which is located mainly in the central part of the deposit in footwall stringer and replacement mineralization. Conversely, zinc and lead occur in the greatest concentration in the massive stratiform sulphides on the fringes of the deposit (e.g., Figs. 12b,c) outboard, and stratigraphically above, the sulphide stringer vein and replacement zones. Structural dismemberment and remobilization of sulphides during deformation, however, likely have disrupted much of the original metal and mineral zonation in the deposit.

Little zoning is evident within the pyrite- and sphalerite-dominant stratiform massive sulphide lenses. Sphalerite-rich mineralization with associated galena and tetrahedrite-tennantite occurs throughout the sulphide lenses in the Lynx and Wolverine zones, as centimetre- to metre-thick zones of poor definition, which alternate with pyrite-dominant massive sulphides. In most places, the entire sulphide interval contains abundant sphalerite, although distribution of the extremely sphalerite-rich zones is erratic. Chalcopyrite distribution is strongly zoned because it is the principal-sulphide mineral in massive replacement-type and stringer vein-type mineralization in the footwall. Elsewhere, chalcopyrite is only a very minor constituent of the overlying stratiform sulphide lenses. Consequently, areas of the deposit, which lack sulphide stringer vein or massive replacement-type mineralization do not contain signifcant chalcopyrite. A notable exception occurs in massive stratiform sulphide

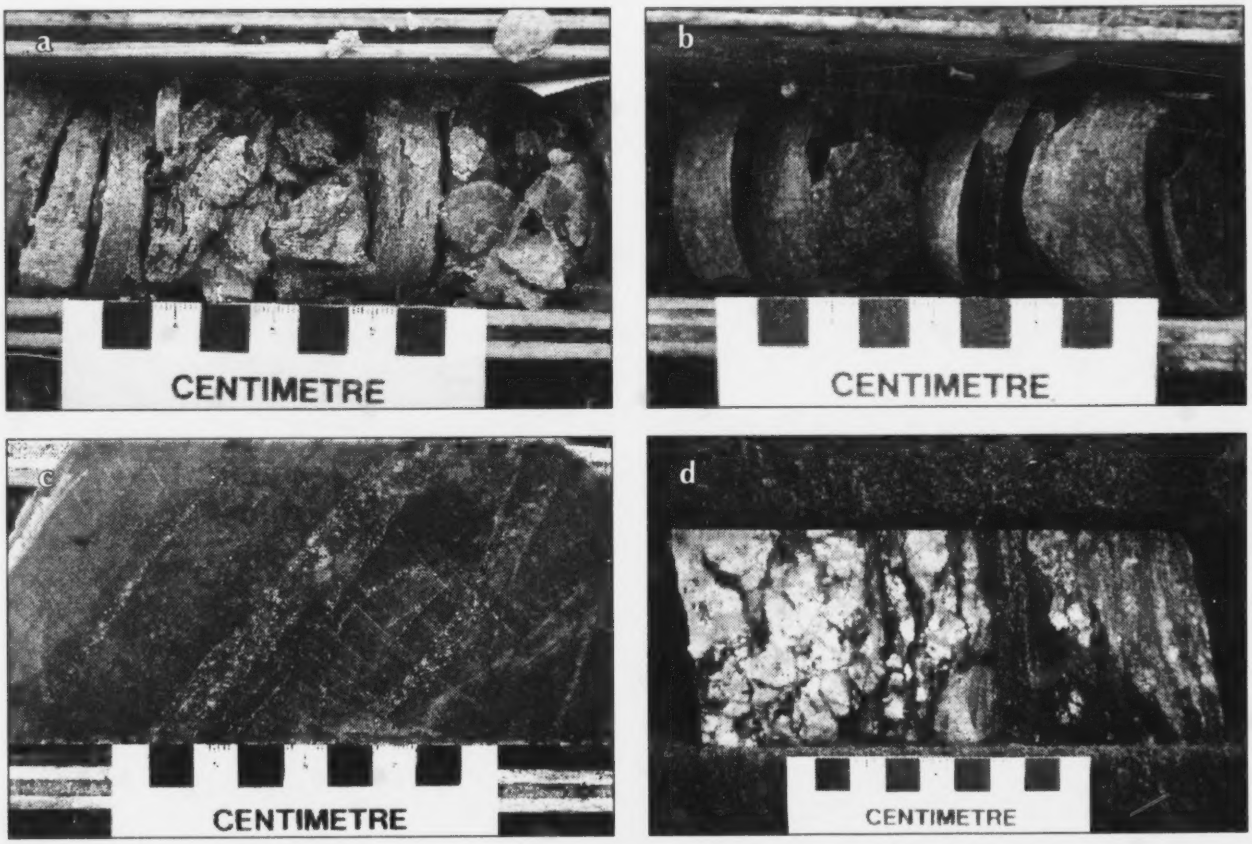

Figure 13. *Photographs of alteration styles: (a) strongly sericitized rhyolitic volcaniclastic rock; (b) chloritized rhyolitic volcaniclastic rock; (c) strongly silicified and sulphide stringer-veined (pyrite and sphalerite) rhyolitic volcaniclastic rock; and (d) carbonatized rhyolitic volcaniclastic rock.*

mineralization forming the northwest portion of the Lynx zone. Here, a 1.3-m-thick zone of chalcopyrite-rich sulphide mineralization forms the base of the massive sulphide lens. This area of elevated copper values is related spatially to an inferred north-northwest-trending growth fault, which may have localized the ascent of mineralizing fluids. The location of this fault is based on the extreme variations in sulphide thickness mapped over short distances. Its position is illustrated in Figure 9.

HYDROTHERMAL ALTERATION

Hydrothermally altered rocks are found predominantly in the immediate footwall to the massive sulphide mineralization, where permeable felsic volcaniclastic rocks have been preferentially altered. Four main styles of hydrothermal alteration are intimately associated with mineralization at the Wolverine deposit (e.g., Figs. 13a-d). The alteration types, in order of decreasing abundance, are (1) sericite, (2) chlorite, (3) silica (quartz), and (4) carbonate. The main features of each are discussed below.

(1) Sericite alteration (Fig. 13a) is characterized by moderate to pervasive development of sericite in fine- to coarse-grained felsic volcaniclastic rocks. Sericite alteration is stratabound and occurs throughout the deposit, both within, below, and lateral to (or outboard of) the zone of chlorite alteration, but occurs most commonly in the footwall to massive sulphide mineralization. Sericite-altered volcaniclastic rocks are intensely foliated (likely due to a ductility contrast with adjacent unaltered rocks?) and contain 40 to 60 vol. % sericite. In the most strongly altered zones, all minerals excluding quartz are completely replaced. Sericite alteration is the most extensive and widespread alteration type, reaching a thickness of 50 m where best developed in the Hump and Wolverine zones. There is a gradual decrease in the intensity of sericite alteration moving laterally away from these zones. Sericite alteration is locally well developed in the Lynx zone, but not as extensively as elsewhere, possibly because there is more variation in the footwall lithologies. Sericite alteration is locally mapped in rocks of the hanging wall, especially on the eastern fringe of the deposit where the stratiform massive sulphide mineralization occurs within rhyolitic volcaniclastic rocks of Unit 1. It should be noted that it is difficult, in places, to distinguish hydrothermal sericite alteration from that which formed in the felsic rocks in response to regional metamorphism and deformation, particularly where the former is only weakly developed. There may be a compositional difference between sericite forming the two types and this is under current investigation.

(2) Chlorite alteration (Fig. 13b) is characterized by the intense development of chlorite in fine- to coarse-grained, felsic volcaniclastic rocks. The result is a dark green chloritized rock with moderately to coarsely flattened felsic volcanic rock fragments with, or without quartz and feldspar crystals. Chlorite alteration is most strongly developed in the Wolverine zone where it occurs in the immediate footwall to the massive sulphide mineralization and is up to 30 m thick. It is widespread in the Hump zone, where it is associated with carbonate alteration and massive sulphide replacement-style mineralization. In most localities where chlorite alteration is present, there is a gradual transition in alteration-types from chlorite-dominant to sericite-dominant with increasing distance from the massive sulphide lens. This zonation can be ascribed to the twin influences of decreasing heat and fluid flow in those areas distal to the main zone(s) of hydrothermal activity (e.g., Lydon, 1988).

(3) Silica alteration (Fig. 13c) is characterized by the pervasive development of fine-grained quartz in rocks immediately adjacent to quartz–sulphide (pyrite >sphalerite >>chalcopyrite) veins. This alteration-type is rare and may be confined to narrow zones associated with hydrothermal fluid conduits. Silica alteration is particularly strong in drill hole WV-97-81, where it extends 5 m below the massive stratiform mineralization (see location on Fig. 9). Here, rhyolite tuff is intensely silicified and contains 3 to 5 vol. % quartz-pyrite-sphalerite veins ranging up to 3 cm in width. In most other localities, sulphide stringer veins are narrower and lack associated silica alteration. In Unit 2, carbonaceous argillites in the hanging wall are locally strongly silicified and contain narrow veins of quartz and pyrite. Petrochemistry of the aphyric rhyolite in the hanging wall indicates that they contain significantly higher SiO_2 than that found in typical rhyolite (S.J. Piercey, unpublished data, 2000). These possible hanging wall alteration phenomena are currently under investigation.

(4) Carbonate alteration (Fig. 13d) is characterized by the development of varying amounts of white calcite, orange-brown ankerite and brown siderite. This alteration-style is commonly associated with chlorite alteration. Carbonate minerals commonly occur as large porphyroblasts ranging up to 2 cm in diameter, which may occupy 20 to 30 vol. % of the rock. This alteration-style occurs with massive sulphide replacement and sulphide-stringer mineralization both in the Hump zone and in the immediate footwall to the massive sulphide mineralization in the Wolverine zone. This unique texture is intimately associated with mineralization, and may have formed by the precipitation of carbonate, which was scavenged from the underlying sediments by hydrothermal fluids. The exact distribution of carbonate alteration is poorly understood at the present time, but widths of individual zones rarely exceed 2 m.

DISCUSSION

The field data presented in this paper, particularly the spatial and temporal association of the sulphide mineralization with felsic volcanic rocks, demonstrate that the Wolverine deposit shares many features with the Kuroko deposits of the Hokuroku district, Japan (e.g., Ohmoto, 1996). The petrochemistry of the felsic volcanic rocks in the Wolverine succession is consistent with formation in an ensialic back-arc basin (Piercey et al., 2000). The ensialic back-arc basin setting and the close association of the sulphide mineralization with black carbonaceous shales and felsic volcanic rocks places the Wolverine deposit in a group of rather unique VHMS deposits, which include those of the Bathurst camp in New Brunswick (e.g., van Staal et al., 1991; McCutcheon, 1992; Goodfellow and Peter, 1996).

In order to gain a better understanding of the volcanic environment in which the Wolverine deposit was generated, further study of the nature and distribution of the host rocks is necessary. Petrographic studies may be used to reveal whether the volcaniclastic rocks of Units 1 and 2, and the fragmental rhyolite of Unit 3, are mass flow deposits (i.e., epiclastic) or pyroclastic in origin. Changes in the thickness of these rocks over the entire deposit may correspond to the location of a volcanic centre. The presence of graphitic argillite in the immediate hanging wall, and extensive carbonaceous argillite in the footwall, implies that starved, anoxic conditions may have prevailed at or near the time of sulphide deposition, and may have had a strong influence on the mineralization process (e.g., Eastoe and Gustin, 1996; Goodfellow and Peter, 1996, 1999). Chemical analyses of the Wolverine shale will be used to investigate this possibility.

A conspicuous feature of the Wolverine massive sulphide mineralization is the lack of a classic 'carrot-shape' copper-rich feeder zone, which typically extends far below the base of the massive sulphide deposit (e.g., Lydon, 1984). Although this is likely due in part to the effects of post-mineralizaton deformation, the relatively large amount of semi-massive replacement-type mineralization is evidence that the footwall volcaniclastic rocks and sediments were sufficiently permeable (unlithified?) to inhibit the formation of fracture-controlled fluid pathways. Rather, fluids selectively mineralized and altered chemically and physically favourable host-rock sequences. This sub-seafloor replacement-style of mineralization is similar to that of the Rosebery deposit, which is hosted in the Cambrian Mount Read 'Volcanics' of Tasmania (e.g., Green, et al., 1981).

To completely understand how the massive stratiform sulphide mineralization formed requires further study of sulphide textures and, in particular, identification of whether the layering in the sulphides is primary (i.e., bedding), or the result of remobilization and recrystallization associated with later tectonism. Preliminary field evidence suggests that the layering may be primary in places, implying that the sulphides likely were resedimented from the edges of a sulphide mound on the sea floor. The presence of primary sulphide breccia (Fig. 10d) provides further evidence for the formation and collapse of a sulphide mound on the ancient sea floor (Lydon, 1988).

FUTURE WORK

Research on the Wolverine deposit is only in its preliminary stages. Future research includes continued petrographic studies of the sulphide mineralization, host rocks, and hydrothermal alteration in combination with isotopic and geochemical characterization of the mineralization and the hydrothermally altered and unaltered host rocks. These studies will define further the temporal and spatial nature of alteration and massive sulphide mineralization. Acquisition of such data will permit the quantification of the physico-chemical conditions of ore formation and place constraints on material transfer processes accompanying hydrothermal alteration. The ultimate aim of the project is to produce a genetic model for formation of the Wolverine deposit and develop exploration criteria that may be applied to the search for further VHMS deposits in the Finlayson Lake district and elsewhere.

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A structural analysis of the upper Swift River area (105B/3), Yukon, Part I: Dan Zn occurrence and implications for sulphide mineralization[1]

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D'el-Rey Silva, L.J.H., Liverton, T., Paradis, S. and Roots, C., 2001. A structural analysis of the upper Swift River area (105B/3), Yukon, Part I: Dan Zn occurrence and implications for sulphide mineralization. *In:* Yukon Exploration and Geology 2000, D.S. Emond and L.H. Weston (eds.), Exploration and Geological Services Division, Yukon, Indian and Northern Affairs Canada, p. 289-300.

ABSTRACT

Marble, calc-silicate rock and pelitic layers of the Ram Creek assemblage surrounding the Dan Zn (± Cu-Pb-Ag) occurrence display ample evidence of a monocyclic structural evolution with three main events of progressive deformation (D_1-D_3). These events developed a tightly folded package of west-northwest-trending tectonites. Primary planar structures (S_0) generally lie sub-parallel to two tectonic foliations (S_1 and S_2), which dip shallowly to steeply southwest. Inter-foliation slip (D_3) resulted in a transverse, sub-vertical foliation (S_3) that dips generally shallowly to moderately north. Cross-sections based on new mapping and fold analysis indicate that similar folds containing stratabound zinc-sulphide mineralization should be present south of the Dan occurrence, as part of regional north-northeast-verging folds or a thrust-fault-repeated succession.

RÉSUMÉ

Les couches de marbre, de silicate calcique et de pélite de l'assemblage de Ram Creek entourant les indices de zinc (± Cu-Pb-Ag) Dan renferment de nombreuses indications révélant qu'elles ont été l'objet d'une évolution structurale monocyclique qui comprend trois principales déformations progressives (D_1-D_3). Ces phases de déformation ont été à l'origine de la formation d'un ensemble de plis fortement serrés formés de tectonites orientées ouest-nord-ouest. Les textures planaires primaires (S_0) sont en général presque parallèles aux deux foliations tectoniques (S_1 et S_2), de pendage sud-ouest faible à prononcé. Le glissement inter-foliation (D_3) a produit une foliation subverticale transversale (S_3) de pendage nord généralement faible à modéré. Les coupes basées sur une nouvelle cartographie et une analyse des plis montrent que des plis similaires renfermant une minéralisation de zinc et de sulfure stratiforme sont vraisemblablement présents au sud des indices Dan. Ils feraient partie des plis de vergence nord-nord-est d'importance régionale ou d'une succession répétée par des failles de chevauchement.

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INTRODUCTION

This paper reports on detailed structural studies carried out in the Swift River area of stratabound zinc mineralization in southern Yukon Territory. The study area is accessed by mineral exploration roads, about 24 km northwest of the Pine Lake airstrip near the Alaska Highway at kilometre 1162. Massive sulphide mineralization was discovered in the area in 1946 by Hudson Bay Mining and Smelting Co. Ltd., and examined intermittently since then, most recently by First Yukon Silver Ltd., Cominco Ltd. and Birch Mountain Resources (Indian and Northern Affairs Canada, 1993; Burke, 1998). Although the area has been regionally mapped (Poole et al., 1960; Stevens and Harms, 2000) and the Dan area mapped in detail (Bremner and Liverton, 1991), there has been no structural analysis of the complex folds in the mineralized areas. The man-made bedrock exposures described here comprise the east and west showings of the Dan zinc occurrence (also known as the BAR; Yukon MINFILE, 1997, 105B 027), where the largest claim owner is currently First Yukon Silver Ltd. Along the structural trend to the west are the Lucy, Gossan and Atom showings (the latter is the Crescent occurrence, Yukon MINFILE, 1997 - 105B 026). A similar structural study was carried out on the nearby TBMB claims (Fig. 1; D'el-Rey Silva et al., this volume).

REGIONAL GEOLOGY

The western headwaters of the Swift River encompass the northeastern edge of the Dorsey Terrane (Gordey et al., 1991), where it borders on the western edge of the Cassiar Terrane (Fig. 1). Dorsey Terrane is divided into litho-tectonic assemblages (Stevens and Harms, 1996), which in the upper Swift River area include Ram Creek (metavolcanic rocks, meta-siliciclastic rocks, marble and meta-plutonic rocks), Dorsey (predominantly chlorite-muscovite-feldspar-quartz schist), and Swift River (dark argillite and chert, with quartzite intervals) assemblages (note that Dorsey assemblage is a subset of Dorsey Terrane). The assemblages trend southeast, as do intrusions which separate the first two: the Ram stock, a ~ 259 Ma old deformed granodiorite (Stevens, 1996), and a diorite of probable Jurassic age. The contact between Ram Creek assemblage and Cassiar Terrane lies covered beneath the upper Swift River valley, and is thought to be a fault zone. The Dan occurrence is less than 10 km northeast of the Cretaceous Seagull Batholith and less than 2 km southwest of the Cassiar Batholith.

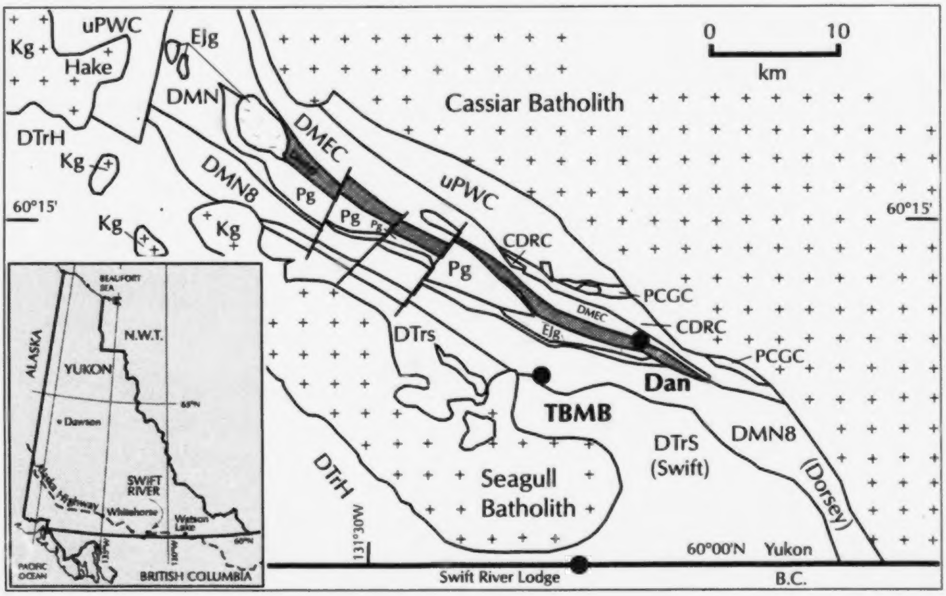

uPWC
Kg
Hake
EJg
DMN
DTrH
Kg
60°15'
Kg
DMN8
Kg
DMEC
Pg
Pg
Pg
uPWC
Cassiar Batholith
0
10
km
60°15'
CDRC
Pg
PCGC
DMEC
EJg
CDRC
PCGC
DTrs
Dan
TBMB
DTrS
(Swift)
DMN8
(Dorsey)
DTrH
Seagull
Batholith
131°30'W
60°00'N
Yukon
B.C.
Swift River Lodge
BEAUFORT SEA
N.W.T.
ALASKA
YUKON
Dawson
SWIFT RIVER
Alaska Highway
Whitehorse
Watson Lake
PACIFIC OCEAN
BRITISH COLUMBIA

Figure 1. Location of the Swift River area in southern Yukon. Geology adapted from Gordey and Makepeace (1999). Labelled units are: Kg – Cretaceous intrusions; EJg – Jurassic intrusions; Pg – Ram stock (Permian); DTrH – Klinkit assemblage; DTrS – Swift River assemblage; DMN8, DMN – Dorsey assemblage; DMN9 – Ram Creek assemblage (shaded); and rocks of the Cassiar Platform, including: DMEC – Mid-Paleozoic argillite; CDRC, PCGC – Lower Paleozoic carbonate; and uPWC – Late Proterozoic clastic rocks. The area of Figure 2 is covered by the dot marking the Dan occurrence. (The TBMB claims, the subject of D'el Rey Silva et al. (Part II, this volume) are also shown).

GEOLOGY OF THE SWIFT RIVER AREA

The relatively low elevation showings of the Dan occurrence are hosted by the Ram Creek assemblage, containing metavolcanic rocks (felsic, intermediate and mafic protoliths are suspected), argillite, meta-siltstone and marble, all of which have been deformed and metamorphosed to at least upper greenschist facies. Compositional contacts are the only primary feature remaining, with the exception of probable igneous-flow texture (fiamme) observed in thin sections of metavolcanic layers (S. Gordey, pers. comm., 1995) and beta-quartz phenocrysts (pers. comm., First Yukon Silver Resources Ltd., 1995; pers. comm., Birch Mountain Resources Ltd., 1998). Marble is only abundant in the vicinity of the Dan occurrence, but was intersected in drill core to the west (beneath Lucy showing; T. Liverton, pers. comm., 2000). In the area of the Dan occurrence, the pelitic rocks are a contact-metamorphosed succession of garnet-diopside-actinolite calc-silicate hornfels, and the marble contains bands of diopside and garnet. Disseminated to banded and massive pyrrhotite and magnetite with some sphalerite, chalcopyrite and pyrite is distributed in pods and blebs along the deformed contact between white and green calc-silicate rock (possibly meta-tuff) and the marble. The sulphide layers appear to follow a branching system of reverse faults and steeply dipping cross-faults of minor displacement (Bremner and Liverton, 1991). At other occurrences, the mineralization style is similar but the host rock varies: dark metavolcanic rock predominates at the Lucy showing, whereas at the lower Atom showing, the alternating tectonic bands of garnet-epidote and quartz-chlorite are similar to non-mineralized parts of the Dan showings. Another mineralized area, 4 km southwest of Dan (the TBMB claims; Yukon MINFILE, 1997, 105B 029) is discussed in D'el Rey Silva et al. (Part II, this volume). Previously all the mineralization was interpreted as skarn (Abbott, 1986; Bremner and Liverton, 1993), but is here considered sedimentary (possibly volcanic-) exhalative, deformed and subsequently contact metamorphosed by much later intrusions.

METHODS

The Dan occurrence has eastern and western showings (Fig. 2) that are outcrops enhanced by bulldozer excavation and pressure washing (H. Hibbing and D. Schellenberg, pers. comm., 1990). The resulting surface is roughly planar to the north-facing slope (Fig. 3) that is largely controlled by shallowly dipping fractures.

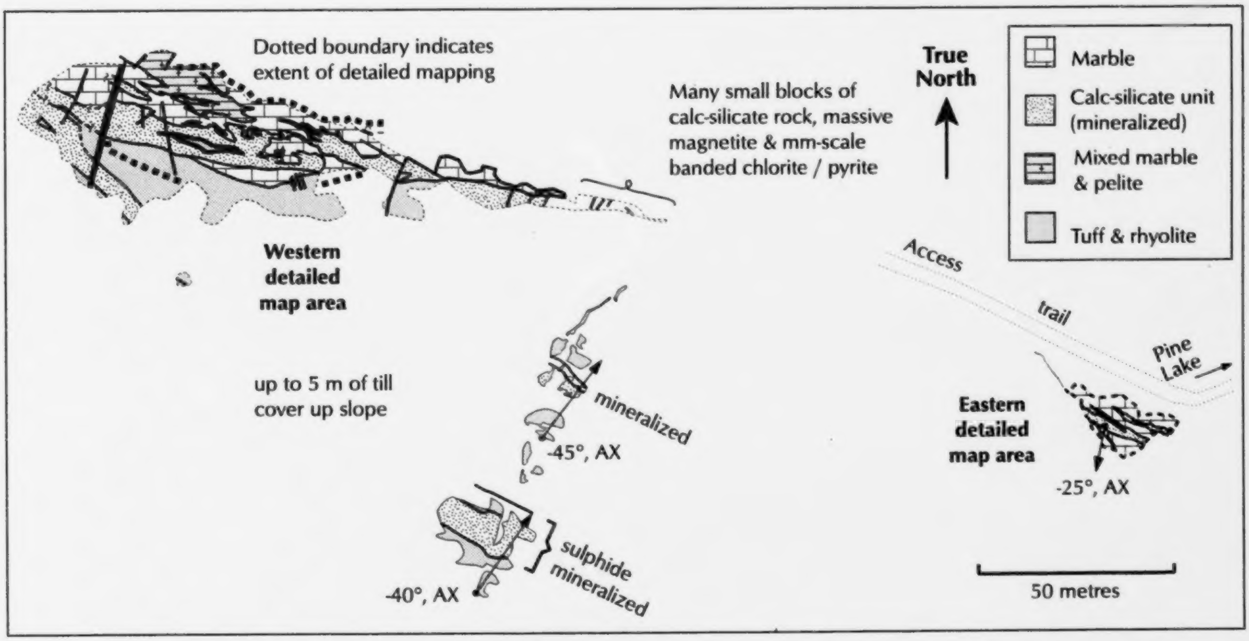

Dotted boundary indicates extent of detailed mapping
True North
Many small blocks of calc-silicate rock, massive magnetite & mm-scale banded chlorite / pyrite
Marble
Calc-silicate unit (mineralized)
Mixed marble & pelite
Tuff & rhyolite
Western detailed map area
Access trail
Pine Lake
up to 5 m of till cover up slope
mineralized
-45°, AX
Eastern detailed map area
-25°, AX
sulphide mineralized
-40°, AX
50 metres

Figure 2. *Exposure of the Dan Zn-Pb-Ag occurrence, indicating the western and eastern parts (Figs. 4a and 5) that have been mapped in detail by the second author during 1990, 1996 and by the first author during this study. Arrows on three exposures indicate drill holes with plunge and core size (AX).*

Mapping at 1:100 and 1:200 scales was performed with the aid of a plane table, alidade, and tape, and fold hinges, fold limbs, contacts, and intersecting structures were precisely located. Contacts and folds were drawn directly on the plane table whilst still at the outcrop; such documentation helped the authors understand the effects of fold superposition, particularly in the western part of the Dan. At every change in direction of the contact between the marble and calc-silicate rock, an F_1, F_2, or both types of fold could be identified. Samples of different rock units and different types of ore were collected in the field. Studies of the petrology and mineralogy of the host rocks, as well as analyses for stable and radiogenic isotopes (O, C, Sm-Nd) are in progress.

The resulting geological maps are simplified in Figures 4a and 5. Some F_1 and several F_2 folds are large enough to show on the maps. All attitudes mentioned herein follow the dip-direction method.

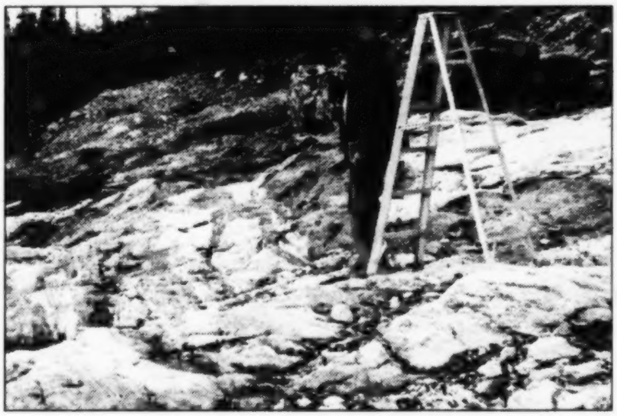


Figure 3. *Eastward view of washed bedrock at western showing, showing a thin, dark calc-silicate layer interleaved with light marble. The ladder was used in taking the photograph of the fold shown in Figure 8.*

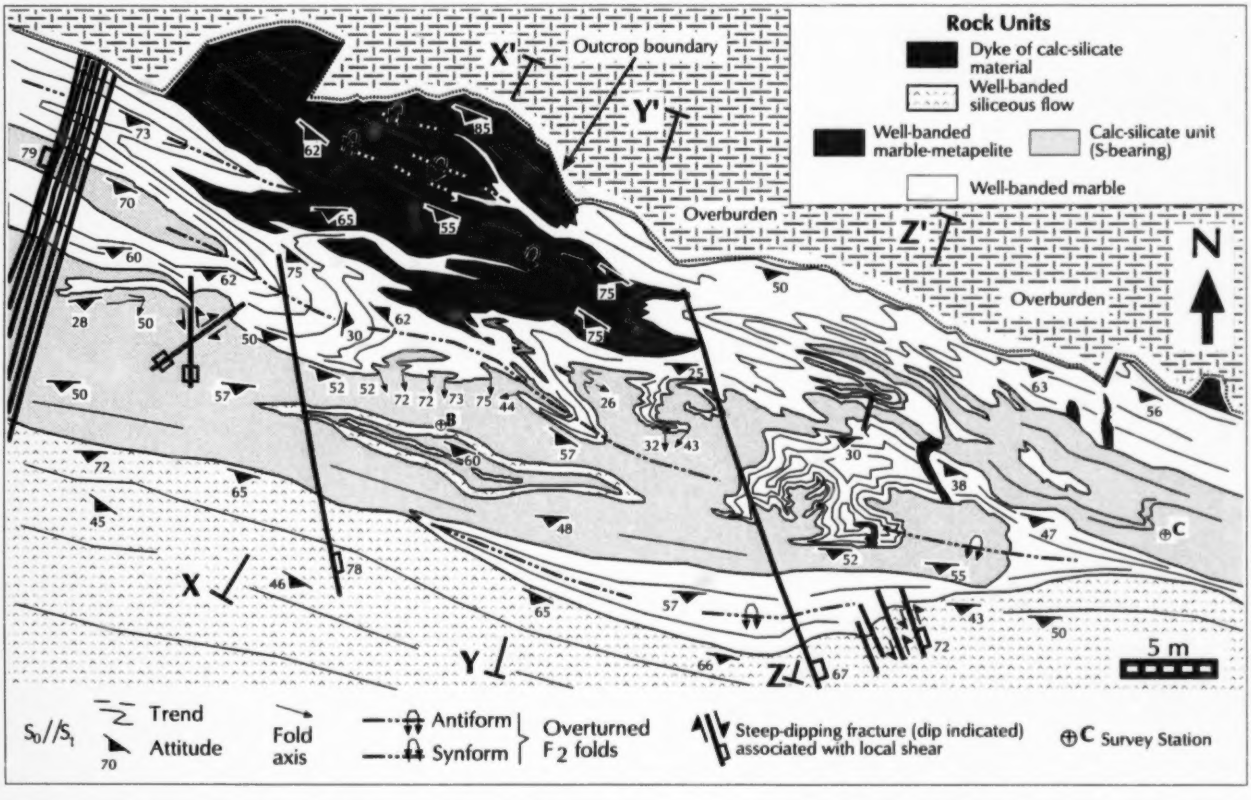

Rock Units
Dyke of calc-silicate material
Well-banded siliceous flow
Well-banded marble-metapelite
Calc-silicate unit (S-bearing)
Well-banded marble
Outcrop boundary
Overburden
X'
Y'
Z'
X
Y
Z
B
C
N
5 m
$S_0//S_1$
Trend
Attitude
70
Fold axis
Antiform
Synform
Overturned F2 folds
Steep-dipping fracture (dip indicated) associated with local shear
Survey Station

Figure 4a. *Lithostructural map of the western part of the Dan occurrence (reduced from 1:200-scale mapping) showing cross-section locations (XX', YY' and ZZ').*

SUMMARY OF STRUCTURES AND

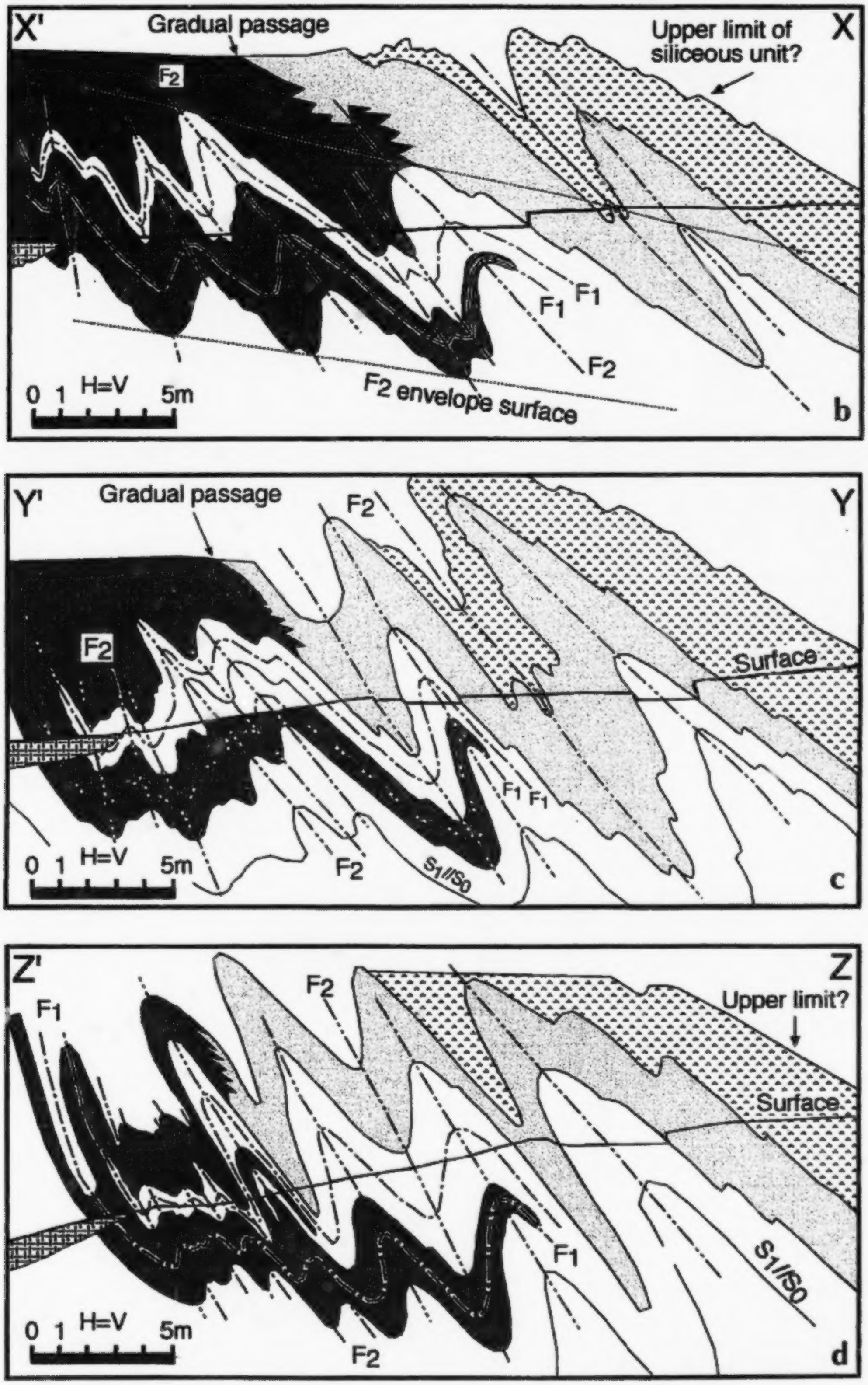

X'
Gradual passage
Upper limit of siliceous unit?
X
F2
F1
F1
F2
0 1 H=V 5m
F2 envelope surface
b
Y'
Gradual passage
F2
Y
F2
Surface
F1
F1
0 1 H=V 5m
F2
S1//S0
c
Z'
F1
F2
Z
Upper limit?
Surface
F1
S1//S0
0 1 H=V 5m
F2
d

Fig. 4b,c,d. *Vertical cross-sections for the western part of the Dan occurrence. Structures related to the D_3 event, such as sub-vertical fractures and sub-vertical faults, have been omitted for clarity. H = V: horizontal = vertical.*

DEFORMATION

Structures in the studied area result from two events of highly ductile deformation (D_1-D_2) and from a late event of brittle-ductile deformation (D_3). The two earlier events imprinted several micro- to mesoscopic-scale structures on the sedimentary layering (S_0), such as folds (F_1, F_2) and their associated planar and linear fabric elements: axial plane foliations (S_1, S_2), intersection lineations (L_{1-0}, L_{2-1}) and fold axes (B_1, B_2).

As a consequence, the area consists of a packet of east-southeast-trending S-tectonites containing three planar foliations ($S_0//S_1//S_2$) commonly sub-parallel and dipping shallowly to steeply to the southwest. Linear structures such as L_1, L_2-1, B_1, B_2 are also sub-parallel and trend southeast, with a gentle plunge commonly to northwest or southeast.

The D_3 event developed folds (F_3) with their associated planar structures, such axial planar foliation (S_3). A set of shallowly dipping fracture planes (S_{3a}) are tertiary fractures that exacerbated glacial erosion. Linear structures of D_3 (fold axis and intersection lineation) are controlled by the dip of $S_0//S_1//S_2$. They are not discussed further because they do not affect the distribution of rocks and mineralization.

PRIMARY LAYERING (S_0)

The intercalation of metasedimentary and metavolcanic rocks with markedly different compositions occurs on scales between 1 and 10 m. On a small-scale, S_0 is marked by cm- to dm-thick beds of different colour within each sedimentary unit. For example, within the marble unit, beds of grey meta-pelites are intercalated with dominant beds of white marble.

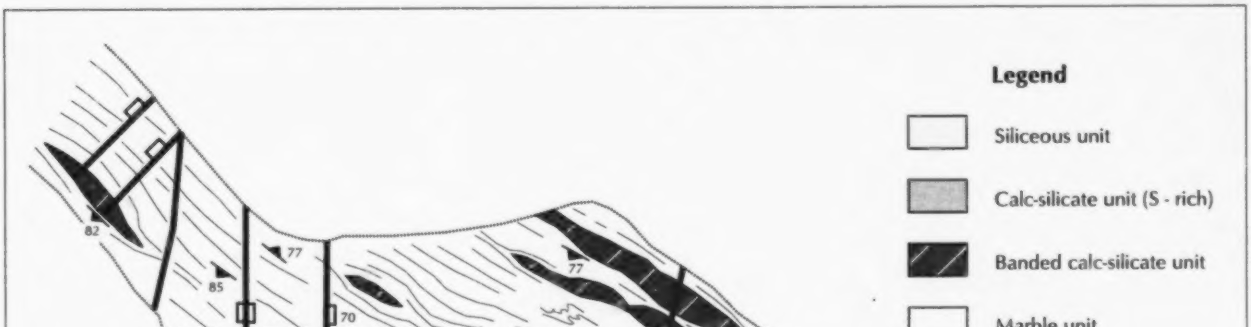

Legend
Siliceous unit
Calc-silicate unit (S - rich)
Banded calc-silicate unit
Marble unit
Outcrop boundary
DH Diamond drill hole
Structural trend (S0//S1)
70 S0//S1 (with dip)
S0//S1 (vertical)
Steep-dipping fracture (dip indicated) with local shear
True North
0 3 m
DH
82
77
85
70
77
75
68
88
78
72
70
66
85
85
81
88
75
66
75
77
74

Figure 5. Lithostructural map of the eastern part of the Dan occurrence, based on 1:100-scale geological mapping.

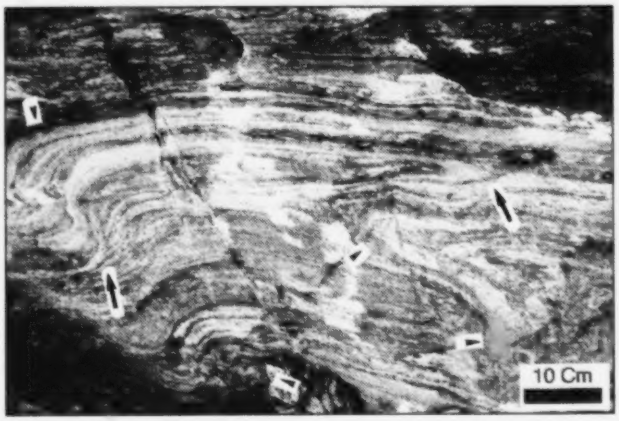


Figure 6. *F_1 folds in the white marble unit of the eastern part of the Dan occurrence. Thick arrows indicate two hinges. The whole package displays $S_0//S_1$ and is co-axially refolded by F_2 folds (other arrows). F_1 and F_2 folds display Z and S asymmetry, respectively.*

THE D_1 DEFORMATION

This event is characterized by isoclinal folds (F_1) and their associated axial planar foliation (S_1). This folding affected S_0 throughout the area and developed a longitudinally continuous packet of well-layered, low-grade metamorphic rocks, within which the F_1 fold hinges can be traced easily in many places. These hinges are contained within the packet of layers and commonly exhibit an amplitude of 0.1-1.0 m, whereas the fold limbs are several metres to tens of metres long. This supports the interpretation that D_1 was an event of very ductile deformation, and the F_1 folds compare well with class 3 folds of Ramsay (1967). F_1 folds have a strong axial planar foliation (S_1) that is sub-parallel to S_0, except in the F_1 hinges, where S_1 cuts across the primary layering (Fig. 6).

S_0-S_1 forms a set of southeast-trending planar structures that dip from 40° to 80° generally southwest, everywhere in the Swift River area. However, the average dip angle of S_0-S_1 is greater in the eastern (Fig. 7a) than in the western part (Fig. 7b) of the Dan. The F_1 fold axes (B_1) plunge shallowly to NW or to SE, in the Dan (Fig. 7g) and also regionally.

The S_1 foliation is commonly defined by flattened crystals of carbonate and quartz, and phyllosilicates such as fine-grained white mica (sericite), chlorite and some biotite. A slaty cleavage is visible in some fine-grained siliciclastic units. The S_1 / S_0 intersection lineation ($L_{1\text{-}0}$) is parallel to the B_1 fold axes (Fig. 7g).

THE D_2 DEFORMATION

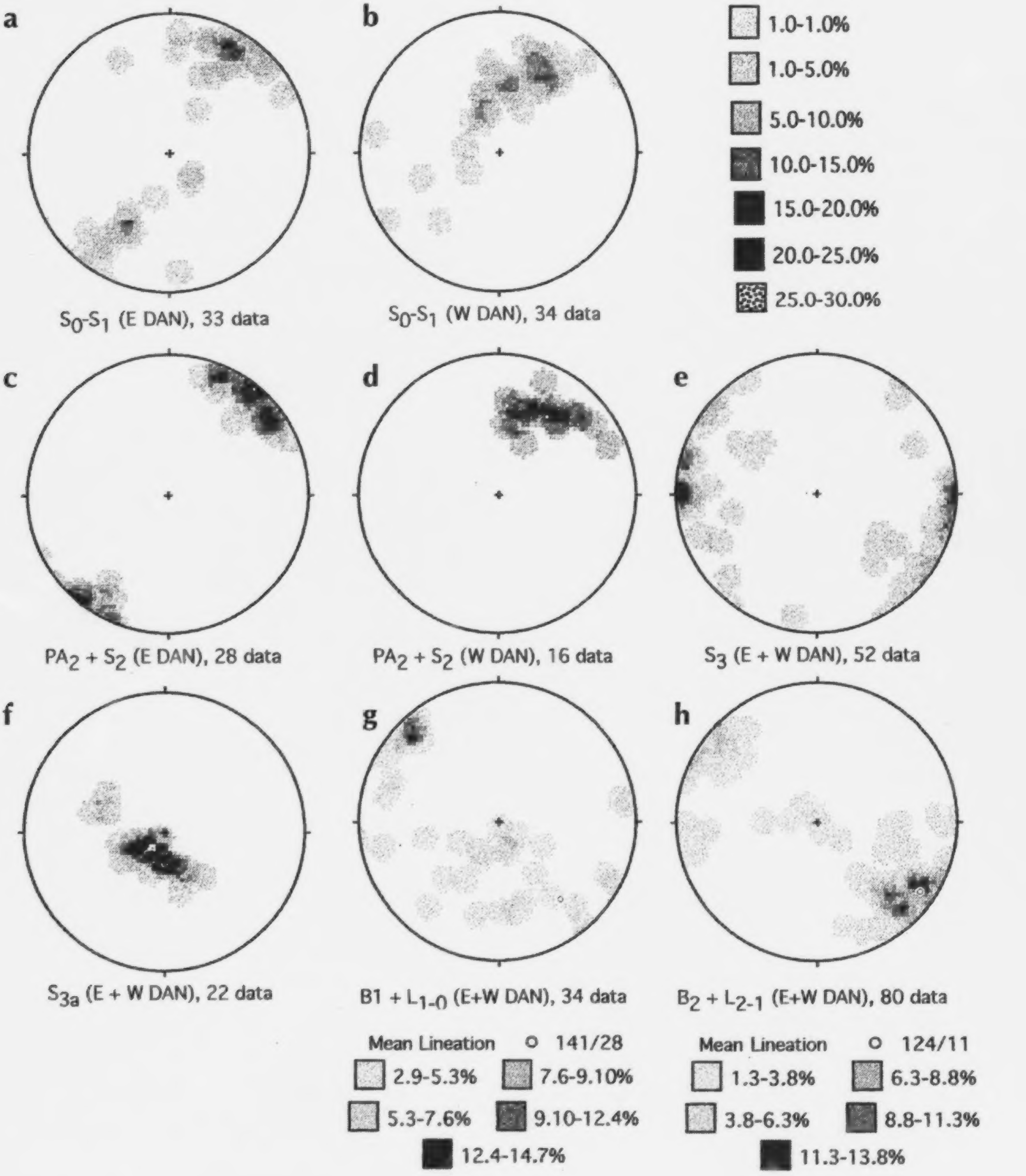
The D_2 event of deformation is defined by several pairs of mesoscopic F_2 folds and their associated axial plane foliation (S_2) that affect S_0 and all D_1 tectonic structures. The F_2 folds are co-axial with F_1 (Fig. 8), as indicated by the S_0-S_1 stereograms (Fig. 7-b). However, by comparison with the stereograms of B_1 + $L_{1\text{-}0}$ and B_2 + $L_{2\text{-}1}$, the poles of B_1 and $L_{1\text{-}0}$ are generally dispersed around southerly directions (Fig. 7g), partly because F_1 are non-cylindrical folds (Williams and Chapman, 1979) may have evolved into sheath folds (discussed later).

The F_2 folds are southeast trending, commonly tight, display m to 10-m scale, and are moderately inclined to up-right (Fig. 8). F_2 axial planes dip between 80° and 90° northeast and southwest in the eastern part of the Dan (Fig. 7c), and around 40°-60° to the southwest in the western part (Fig. 7d). In contrast, the fold axes exhibit a plunge to northwest or southeast in both parts of the area (Fig. 7h). These folds have a strong and penetrative axial planar foliation (S_2) with similar orientation and associated mineralogy as S_1. The authors therefore interpret similar conditions of deformation during D_1 and D_2. The intersection between planes of S_2 with S_1 and S_0 develops a penetrative lineation that overprints $L_{1\text{-}0}$ in most of the area. It is generally hard to separate these two lineations in the field, but both may be identified locally.

The F_1 and F_2 folds are difficult to distinguish because their respective structures are generally parallel. Numerous examples of fold interference were found in the mapped area. During mapping, a fold was identified as F_1 only if it could be shown to be affected by another fold (F_2), although this method is equivocal in some cases.

SHEATH FOLDS AND THE FOLD INTERFERENCE MAP PATTERN

Sheath folds are a common feature at the Dan occurrence and can be identified along folded contacts. Sheath folds are tight to isoclinal and show hinge lines bent more than 90°, resulting from superposition of fold phases or very high strain on folds with curving hinges (Ramsey and Huber, 1987, p. 638). The F_1 sheath folds at the Dan occurrence are best observed between the marble and calc-silicate units in the western part of the study area where they are 1-3 m in amplitude (perpendicular to the axis of the sheath B_1 + $L_{1\text{-}0}$; Fig. 9).



S_0-S_1 (E DAN), 33 data

S_0-S_1 (W DAN), 34 data

$PA_2 + S_2$ (E DAN), 28 data

$PA_2 + S_2$ (W DAN), 16 data

S_3 (E + W DAN), 52 data

S_{3a} (E + W DAN), 22 data

B1 + L_{1-0} (E+W DAN), 34 data

$B_2 + L_{2-1}$ (E+W DAN), 80 data

Figure 7. *Lower hemisphere Schmidt equal area density stereoplots for: (a-f) poles to: planar structures developed during D_1 - D_3; and (g,h) main linear structures developed during D_1 and D_2. Sources are eastern and western showings of the Dan occurrence, as noted.*

The interpretation that the sheaths are F_1 folds is based on the observation that the axial plane of the sheaths dip at intermediate angles to south-southwest, sub-parallel to the dip of the layers, and that the sheath folds are affected by F_2 folds of dm- to m-scale. Sheath folds of F_2 have not been identified. The repetition of layers in outcrop suggests large-scale co-axial folds, which are used in drawing north-northeast-trending cross-sections.

VERTICAL CROSS-SECTIONS

The vertical cross-sections of the western Dan showing depend upon an interpretation that the layers of marble and pelitic material (in the north) undergo a metamorphic facies transition southward into the calc-silicate unit. This gradual transition is consistent with the observation that they are spatially related in the centre of the western part of the Dan (Fig. 4b); both layers are in contact with the marble unit; both lie along the same trend, and are separated by a few metres. The internal consistency of structural observations allows us to construct other cross-sections up plunge to the west.

The sections display a syncline-anticline pair of isoclinal F_1 folds for which the axial planes dip generally at low angle to south-southwest, but steeper dips are also common due to several F_2 folds with axial planes dipping 45°-75° south-southwest. The enveloping surfaces of the F_2 folds are interpreted to dip shallowly to the south-southwest, parallel to the hinges of F_2 antiforms and synforms.

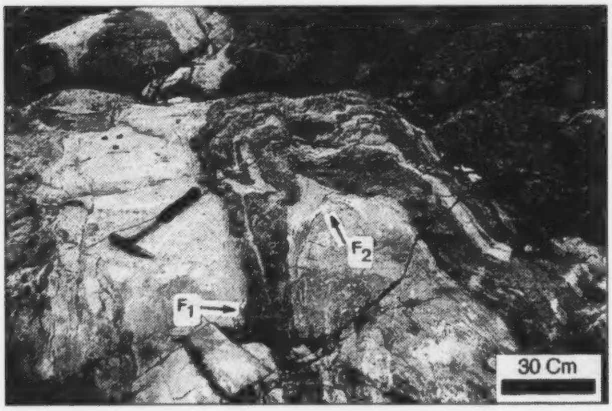


Figure 8. *A thin layer of calc-silicate rock (dark) interleaved with the marble unit (white) indicates F_1 x F_2 co-axial interference pattern. Note the long limbs of F_1 folds refolded by F_2. From the eastern end of the western showing of the Dan occurrence. Larger view shown in Fig. 3.*

Actually, a sequence of m-scale folds in the part of the outcrop close to survey station C (right side of Fig. 5a) implies that the sulphide-bearing layers structurally overlie the marble unit in that outcrop. The intense ductility during D_1 and D_2, coupled with the presence of sheath folds visible at surface (and are likely present in the sub-surface) preclude fully balancing the cross-sections.

The outcrop pattern of the layers record, in map view and in cross-section, progressive folding (F_1 + F_2) with a general vergence to north-northeast. As a consequence, the layers became interleaved on a scale compatible with the thickness of the original beds (cm-dm), because the F_1 folds are isoclinal and the length of their limbs is great compared to the wavelength, particularly if compared to that exhibited by the F_2 folds.

THE D_3 DEFORMATION

This event imprinted folds (F_3), axial plane foliations (S_3), and a set of low-angle-dipping fracture planes (S_{3a}) that affect the D_1-D_2 tectonites in a sub-perpendicular relationship that is systematic across the study area, although D_3 structures are not relevant to spatial distribution of the layers.

The F_3 folds (Fig. 10) are gentle to open, with an S_3 axial plane foliations all trending south, on average, with a steep to sub-vertical dip to westerly and easterly directions, as statistically demonstrated for the eastern and western parts of the Dan occurrence (Fig. 7e). The

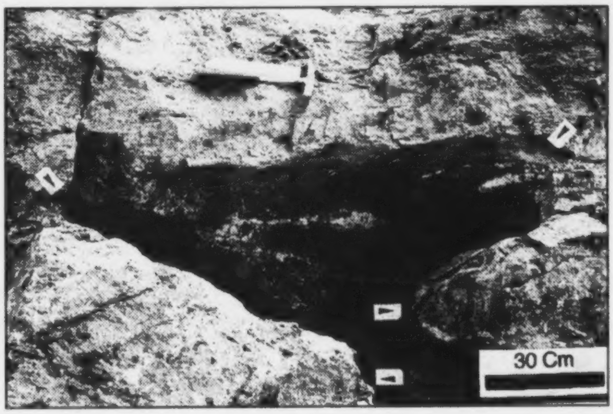


Figure 9. *Eroded hole left by m-scale core of an F_1 sheath fold that affects calc-silicate rock and marble. The four F_1 hinges indicated by the arrows all plunge about 72° to the south-southeast.*

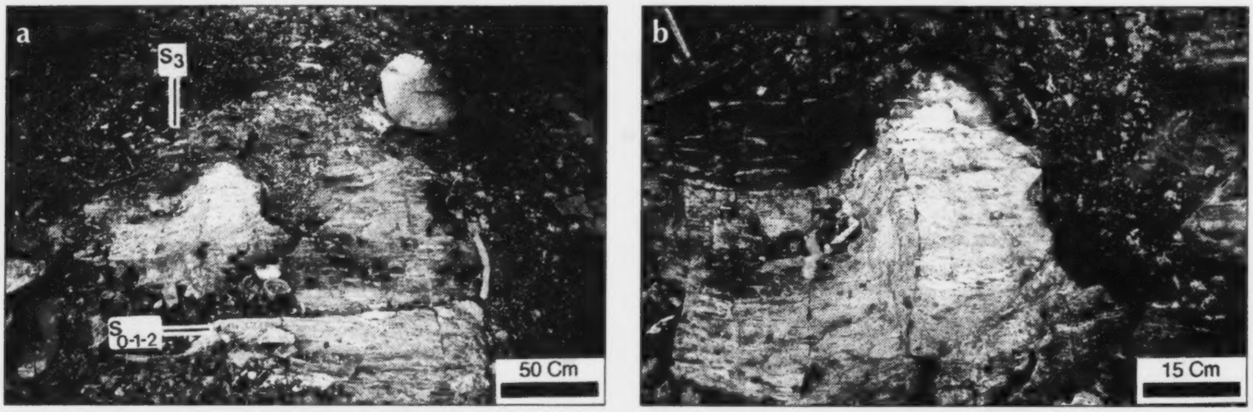


Figure 10. *(a) Southward view of siliceous (light) and calc-silicate (dark rock) tectonites, which display a east-southeast-trending anisotropy composed of* S_0*,* S_1 *and* S_2*. All are sub-parallel to surface (labeled* $S_{0\text{-}1\text{-}2}$ *in the picture), and affected by open to tight* F_3 *folds associated to a well developed, northerly trending, sub-vertical* S_3 *foliation, shown in detail in (b). Note geometry of* F_3 *and the pressure-solution-type* S_3 *foliation.*

folds are sub-vertical bends that affect the anisotropic packet described in the previous sections, so the fold axes and the intersection lineation (B_3 and $L_{3\text{-}2/1/0}$) generally plunge steeply to the south, as it is controlled by the dip of S_0, S_1, or S_2, or even by the dip of all of these, together. The F_3 bends are generally 1 m in size, and commonly display a kink-style.

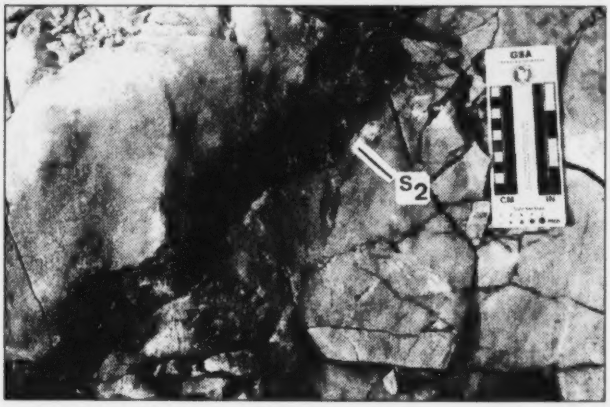


Figure 11. *Dyke of calc-silicate material fills a north-trending extensional fracture in the marble unit, western part of the Dan occurrence. The dyke cuts across* D_1*-*D_2 *structures (*S_2 *foliation is labeled), but is also affected by dm-scale folds and crosscut by their axial plane foliation, both developed late in the* D_2 *event. The plunge of the fold axis (and dyke) is sub-vertical, controlled by the dip of the extension fracture.*

Two sets of D_3 planar foliations are common in the study area. The S_3 foliation is generally a well developed, sub-vertical, spaced cleavage locally displaying a component of pressure solution. The S_{3a} foliation is a spaced cleavage that trends generally west-northwest and dips shallowly to the north (Fig. 7f). The ubiquitous S_3 foliation is not always associated to F_3 folds. The west end of the western outcrop of the Dan is marked by a closely spaced set of S_3 planes (Fig. 4a). The layers are so intensely crosscut that they give the impression of a fault zone although no significant displacement was determined. Carbonate veins are also found along the planes of S_3 and S_{3a}.

In the western part of the Dan a south-trending sub-vertical set of brownish green dykes (Fig. 11) cuts S_1-S_2 and is affected by dm- to m-scale folds with sub-vertical axial planes and vertical fold axes that the authors interpret as late S_2.

CONCLUSIONS

The trenches in the lower part of the Dan occurrence are along the normal limb of a major F_2 fold, which is aligned with other F_1 and F_2 folds. The authors suggest that additional stratiform mineralization could be present in folds up slope to the south of the Dan, beneath overburden. It is a new strategy for mineral exploration in the upper Swift River area.

The F_3 folds and the S_3 foliation may be understood in terms of a layer-parallel compression that took place as soon as the rocks in the area attained the east-southeast regional trend with dips to south. The rocks then behaved as a more competant anisotropic package. The authors envisage a progressive evolution of deformation for D_1-D_3 in the upper Swift River area in a single tectonic cycle. The attitude of the dykes and their shortening by an overall N-S compression illustrate the orientation of maximum compressive stress. In contrast, the S_{3a} foliation is sub-horizontal and may have assisted erosion. Hence S_{3a} planes control the slope of the outcrop.

ACKNOWLEDGEMENTS

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A structural analysis of the upper Swift River area, southeast Yukon (105B/3), Part II: The TBMB claims and implications for the regional geology[1]

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ABSTRACT

The TBMB claim group, 4 km southwest of the Dan occurrence in the upper Swift River area of stratiform zinc occurrences, reveals the nature of the host rocks and style of folding. A train of east-southeast-trending, east-northeast-verging, km-scale F_1 overturned anticlines and synclines dominates the area. These folds clearly control the distribution of low metamorphic grade tectonites (in map and vertical cross-sections) and a structural model allows definition of general stratigraphy of the TBMB and BOUND claim areas. A lower, an intermediate, and an upper unit of siliciclastic metasedimentary rocks are separated by two intervening units of base-metal-sulphide-bearing strata (acid to intermediate metavolcanic rock and marble, respectively). Based upon the repetitive F_1 folds (possibly associated with thrust faults) and the similarity of rock types in the TBMB and Dan areas, the authors propose a structural linkage between them.

RÉSUMÉ

Une étude structurale effectuée dans la région de l'indice TBMB, à 4 km au sud-ouest de l'indice Dan, dans la région du cours supérieur de la rivière Swift où se trouvent des indices de zinc stratiformes, a permis d'apporter des éclaircissements quant à la nature du plissement et les roches encaissantes. Un cortège d'anticlinaux et de synclinaux F_2 déversés, d'importance kilométrique, orientés est-sud-est et de vergence est-nord-est prédomine dans la région. Ces plis contrôlent nettement la répartition des tectonites de faible degré de métamorphisme (voir carte et coupes verticales) et un modèle structural permet de définir la stratigraphie générale de la région des indices TBMB et BOUND. Les unités inférieure, intermédiaire et supérieure des roches métasé entaires silicoclastiques sont séparées par deux unités intercalaires de strates renfermant des sulfures de métaux communs (respectivement des roches métavolcaniques acides à intermédiaires et du marbre). La présence de plis F_2 répétitifs (vraisemblablement associés à des failles chevauchantes) et la similarité des types de roches présentes dans les régions de TBMB et de Dan semblent indiquer qu'il existe un lien structural entre celles-ci.

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INTRODUCTION

In the 1940s, prospectors for Hudson Bay Mining and Smelting Co. Ltd. found sphalerite and magnetite in the north-flowing tributaries of the western headwaters of the Swift River; since then at least eight showings have been discovered. Most have mineralogy characteristic of skarn deposits, but this may be a later overprint as a result of syn-tectonic and post-tectonic plutonism. Several aspects of the occurrences suggest possible volcanogenic or exhalative origin, including:

- mineralized horizons traced up to 19 km in strike length; and
- spatial correlation with tuffaceous and volcanic-epiclastic host-rocks.

All mineral showings are in ductile-deformed metamorphic rock. If they are stratiform, resolution of the stratigraphy is of utmost importance in exploration. However this stratigraphy can only be resolved with the aid of detailed structural analysis. Once the structural style is known, it may be possible to predict the location of buried or blind mineralization.

This paper presents the results of detailed geological mapping in the vicinity of the TBMB and BOUND claims (Munson occurrence; Yukon MINFILE 1997, 105B 029). The structures are then compared with those described in a companion study of the Dan occurrence (D'el-Rey Silva et al., Part I; this volume) and their relationship is discussed.

REGIONAL GEOLOGY

The mineralized occurrences lie within late Paleozoic strata of the Yukon-Tanana Terrane (Fig. 1). In this area, four

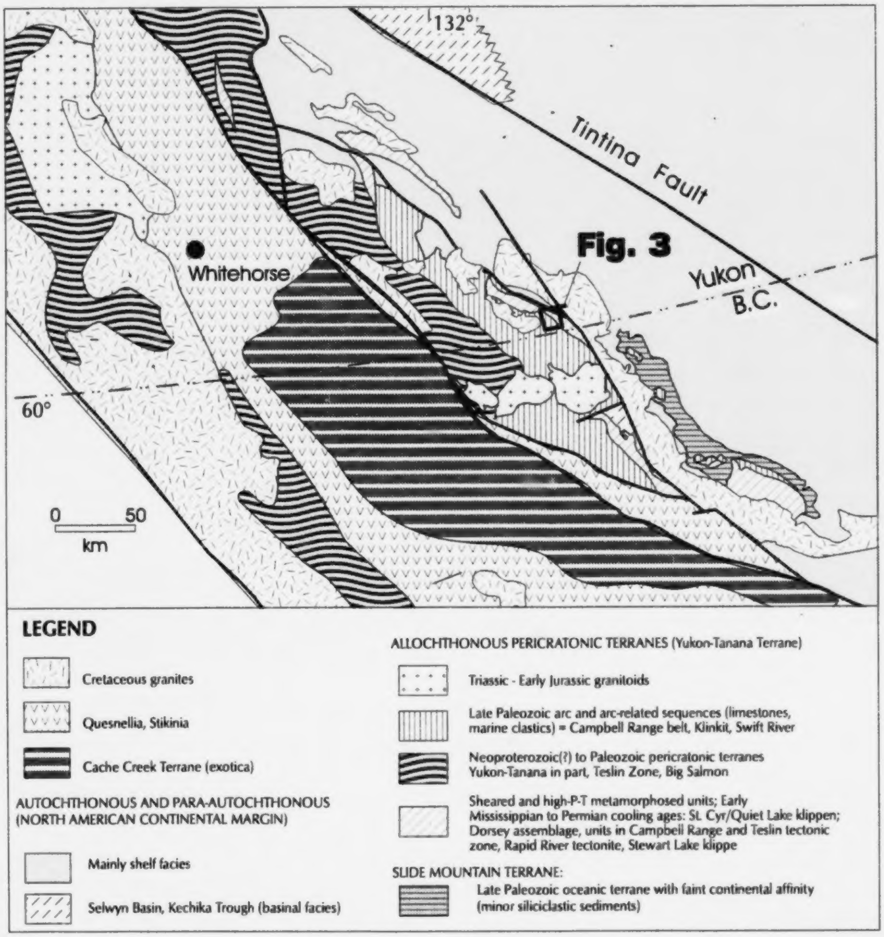

132°
Tintina Fault
Fig. 3
Whitehorse
Yukon
B.C.
60°
0
50
km
LEGEND
Cretaceous granites
Quesnellia, Stikinia
Cache Creek Terrane (exotica)
AUTOCHTHONOUS AND PARA-AUTOCHTHONOUS (NORTH AMERICAN CONTINENTAL MARGIN)
Mainly shelf facies
Selwyn Basin, Kechika Trough (basinal facies)
ALLOCHTHONOUS PERICRATONIC TERRANES (Yukon-Tanana Terrane)
Triassic - Early Jurassic granitoids
Late Paleozoic arc and arc-related sequences (limestones, marine clastics) = Campbell Range belt, Klinkit, Swift River
Neoproterozoic(?) to Paleozoic pericratonic terranes Yukon-Tanana in part, Teslin Zone, Big Salmon
Sheared and high-P-T metamorphosed units; Early Mississippian to Permian cooling ages: St. Cyr/Quiet Lake klippen; Dorsey assemblage, units in Campbell Range and Teslin tectonic zone, Rapid River tectonite, Stewart Lake klippe
SLIDE MOUNTAIN TERRANE:
Late Paleozoic oceanic terrane with faint continental affinity (minor siliciclastic sediments)

Figure 1. *Generalized terrane map for northern British Columbia and southern Yukon (enlarged from Nelson et al., 2000). The Swift River district lies at the northeast edge of allochthonous pericratonic terranes, generally referred to as Yukon-Tanana Terrane.*

lithostratigraphic assemblages have been recognized (Stevens and Harms, 1996, 2000; Roots et al., 2000; Fig. 2): Swift River, Klinkit, Dorsey and Rum Creek assemblages. The northern group of showings (including Dan, Lucy, and Atom; see Fig 3) are located along the regional trend of the Ram Creek assemblage. Roots & Heaman (in press) determined that at least some of the interleaved metavolcanic and siliciclastic rocks of the Ram Creek assemblage are older than 340 Ma. In contrast, the southern group of showings (includes the BOUND and TBMB claims) are included in the Dorsey assemblage by Stevens and Harms (2000). The Dorsey assemblage contains a thin, persistent felsic meta-tuff horizon dated 365 Ma (Roots and Heaman, in press) and is regionally more deformed than the neighbouring Ram Creek (to the north) and Swift River (to the south) assemblages. A resistant diorite, believed of early Jurassic age, occupies the contact between the Dorsey and Ram Creek assemblages in this area. Therefore the structural relationship is equivocal here, although in northern British Columbia the Dorsey assemblage overrides the Ram Creek assemblage on a mid-Permian thrust (Nelson et al., 1998).

The Ram Creek assemblage near the Dan occurrence includes mafic to intermediate metavolcanic rocks and discontinuous quartzite, marble and calc-silicate rock.

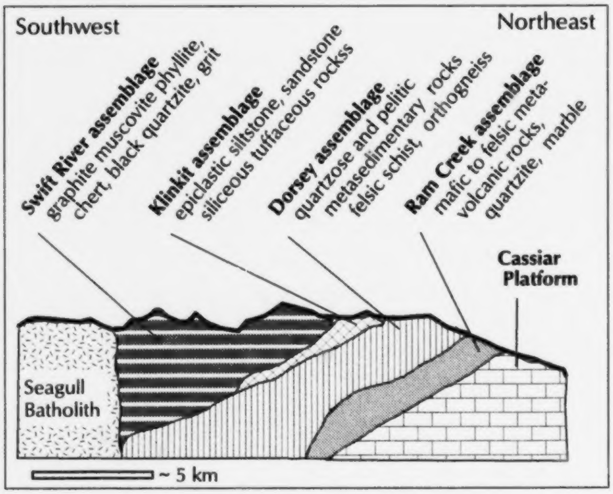

Southwest
Northeast
Swift River assemblage
graphite muscovite phyllite, chert, black quartzite, grit
Klinkit assemblage
epiclastic siltstone, sandstone siliceous tuffaceous rockss
Dorsey assemblage
quartzose and pelitic metasedimentary rocks felsic schist, orthogneiss
Ram Creek assemblage
mafic to felsic meta-volcanic rocks, quartzite, marble
Cassiar Platform
Seagull Batholith
~ 5 km

Figure 2. Schematic cross-section of lithotectonic units in the Swift River district, as described by Stevens and Harms (1996). The Dan occurrence lies within Ram Creek assemblage; the TBMB and BOUND claims lie to the southwest, in the area shown here as Dorsey and Klinkit assemblage.

Dorsey assemblage consists of mafic gneiss structurally overlain by muscovite± biotite schist, quartzite and minor marble. About 10 km east of the TBMB these rocks yielded P-T estimates ranging from 609-732° C and at least 7.7 kbar (Stevens, 1996). In contrast the Ram Creek assemblage, although strongly foliated and sheared, contains some primary depositional features and exhibits retrograde lower greenschist facies metamorphism.

GEOLOGY OF THE TBMB CLAIM AREA

The north-facing alpine cirque of the TBMB (Fig. 4) is underlain by meta-siliciclastic rocks (layered sericite-quartz schist, quartzite, minor phyllite) with m- to dm-scale intercalation of laminated meta-sandstone, meta-siltstone and metavolcanic rock, calc-silicate schist and banded white to pinkish yellow marble. Plane-table mapping and structural interpretation were required in order to separate these rocks into stratigraphic units.

FIELD METHODS

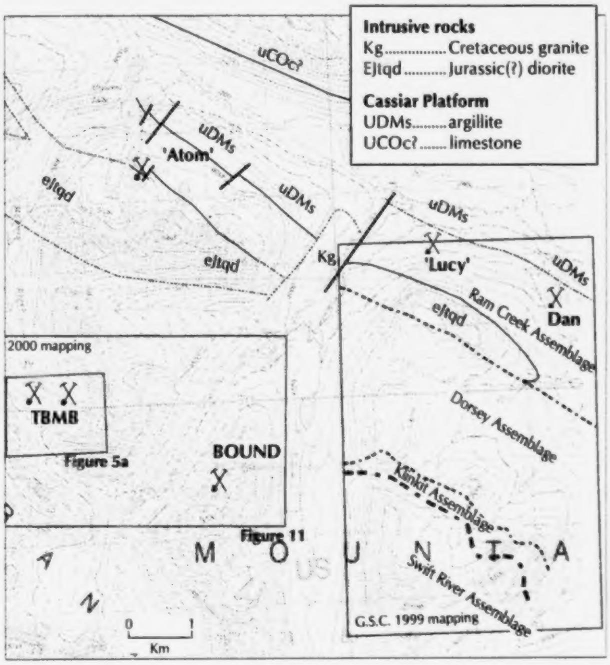

Intrusive rocks
Kg.................Cretaceous granite
EJtqd...........Jurassic(?) diorite
Cassiar Platform
UDMs.........argillite
UCOc?.......limestone
uCOc?
uDMs
'Atom'
eJtqd
uDMs
uDMs
Kg
'Lucy'
uDMs
Dan
Ram Creek Assemblage
eJtqd
Dorsey Assemblage
Klinkit Assemblage
Swift River Assemblage
2000 mapping
TBMB
Figure 5a
BOUND
Figure 11
M O U N T A
0 1
Km
G.S.C. 1999 mapping

Figure 3. Topographic map (NTS 105B/3) of the upper Swift River area indicating the spatial relationship of showings mentioned in the text. Some contacts are shown from regional mapping by Stevens and Harms (2000); faults are heavy dashed lines.

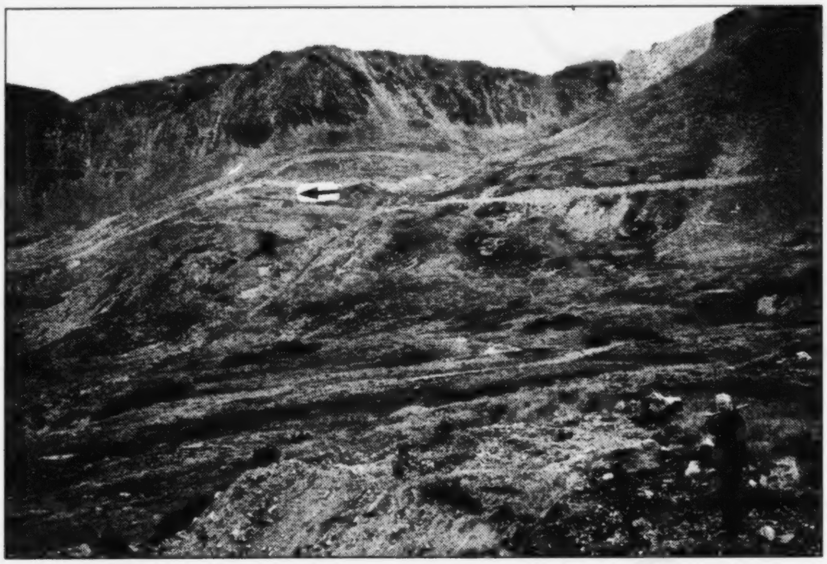


Figure 4: *An east-facing view of the TBMB area, which is mostly underlain by micaceous siliciclastic rocks. The light-coloured marble exposed on the ridge crest at right is in the hinge of the Northern anticline. Trench C (see Figs. 5a and 11) is indicated by the arrow.*

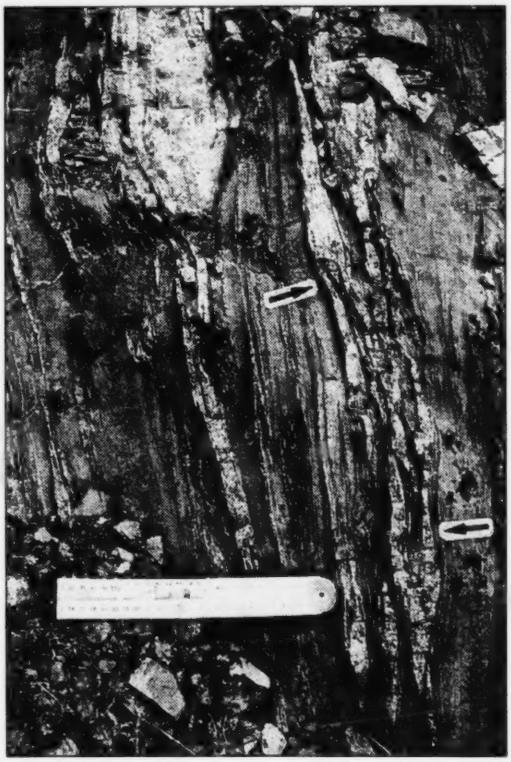


Figure 6. *Interleaved layers showing several F_1 folds (the arrows point to F_1 fold hinges) in light grey marble and light brown metapelites. Attitudes at this location are: B_1 = 060/141°, and $S_0//S_1$ = 214°/70°. Instrument at bottom left is 10 cm long.*

FIELD METHODS

Detailed geological mapping and structural analyses were carried out in an area about 1500 by 1000 m. Figure 5a is based upon 1:2000-scale mapping and shows the location of 59 rock exposures, numbered for reference. These include natural outcrops protruding from rubble as well as three mineral exploration trenches. Using surveying tape and compass, some exposures were mapped in detail (1:100- and 1:200-scale). In addition, a ridge spur about 3 km east of the TBMB (includes the 'BOUND' claim; see Fig. 3) was also investigated.

SUMMARY OF STRUCTURES

All the rocks in the area are polydeformed. The deformation events (D_1-D_3) are similar in scale and style to those of the Dan area (D'el-Rey Silva et al., Part I; this volume). In summary, D_1 developed a pervasive, layer-parallel foliation (S_1) that is axial planar to generally isoclinal F_1 folds from cm- to m-scale (Fig. 6). These structures were affected by a D_2 event, which developed F_2 folds and the axial plane foliation S_2, although S_0/S_1 and S_2 remain sub-parallel in most parts of the area. In several localities the superposition of F_2 on F_1 folds was observed. In detail, it is manifest by a co-axial interference pattern at cm- to dm-scale. Both S_1 and S_2 are defined by sericite, biotite and some chlorite, as well as flattened quartz and carbonate grains. As a consequence, the D_1-D_2 deformation developed a set of greenschist-facies tectonites characterized by an east-southeast-trending

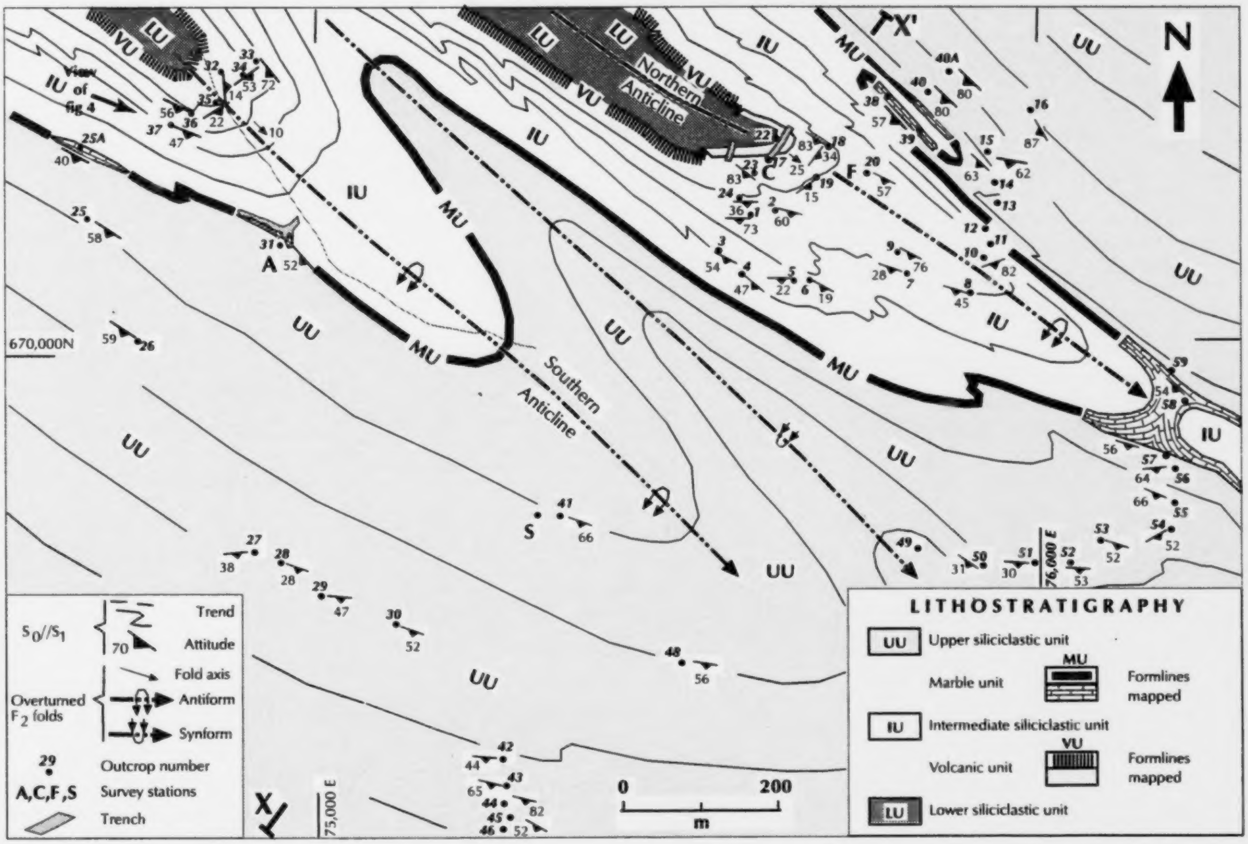

N
X'
LU
VU
IU
MU
UU
Northern Anticline
Southern Anticline
View of fig 4
A
C
F
S
670,000N
75,000 E
76,000 E
X
0
200
m
S0//S1
Trend
70
Attitude
Fold axis
Overturned F2 folds
Antiform
Synform
29
Outcrop number
A,C,F,S
Survey stations
Trench
LITHOSTRATIGRAPHY
UU Upper siliciclastic unit
MU Marble unit
Formlines mapped
IU Intermediate siliciclastic unit
VU Volcanic unit
Formlines mapped
LU Lower siliciclastic unit

Figure 5a. *Summary lithostructural map of the TBMB area with outcrops numbered. Thin lines within units are formlines, drawn along S_0/S_1 structural trends and using the marble and metavolcanic layers as markers. The D_2 and D_3 structures are omitted for clarity. Letters A and C indicate survey stations with nearby exploration trenches.*

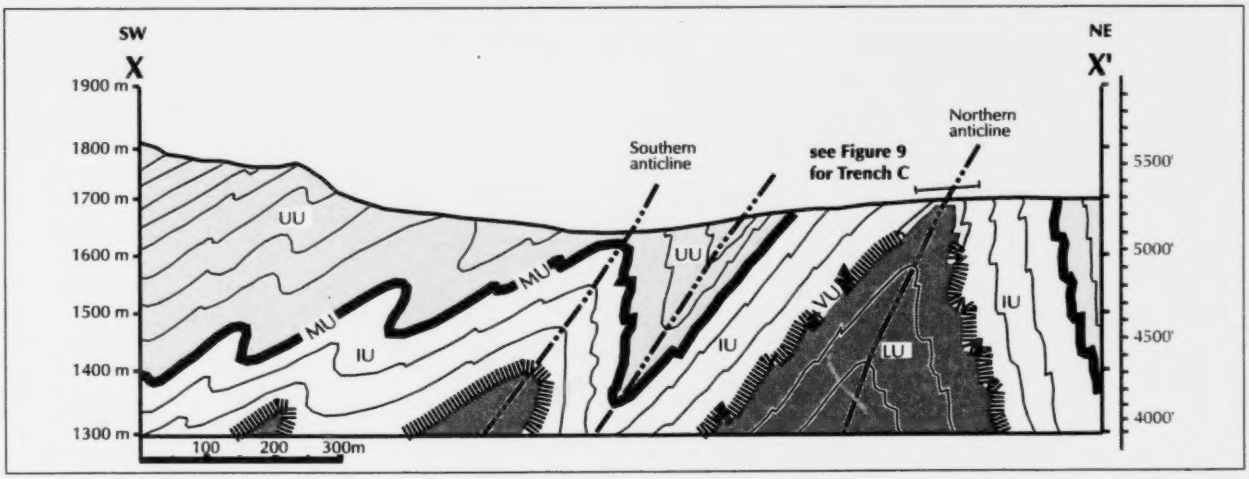
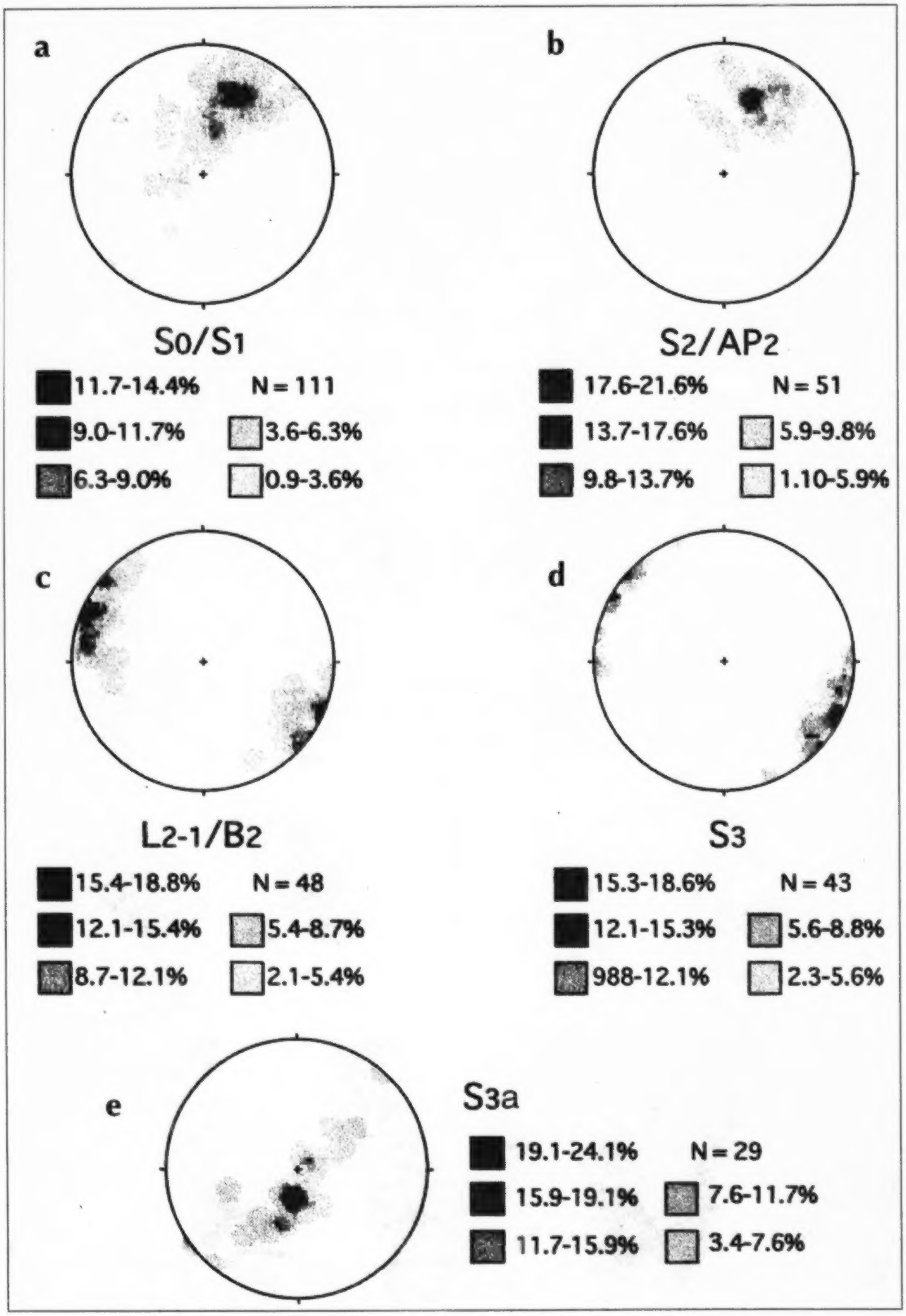

SW
X
NE
X'
1900 m
1800 m
1700 m
1600 m
1500 m
1400 m
1300 m
5500'
5000'
4500'
4000'
Southern anticline
Northern anticline
see Figure 9 for Trench C
UU
MU
IU
VU
LU
100
200
300m

Figure 5b. *Summary vertical section across the TBMB area, based on the demonstration of the Southern and Northern anticlines, with an inferred intervening syncline. Two other kilometre-scale F_2 folds have been interpreted along the normal limb of the Southern anticline. F_1 folds have been omitted, basically for a reason of scale, but they have been noticed in several outcrops. Details in text.*

Figure 7. *Density stereograms of D_2 and D_3 structures in the lower hemisphere of Schmidt-Lambert net. (a) Poles to compositional layering and foliation defined by planar minerals; (b) poles to D_2 penetrative foliation and axial planes of minor folds; (c) intersection lineation of S_1 and S_2 and second phase fold axes (B_2); (d) poles to third phase axial plane foliation; (e) poles to spaced cleavage.*



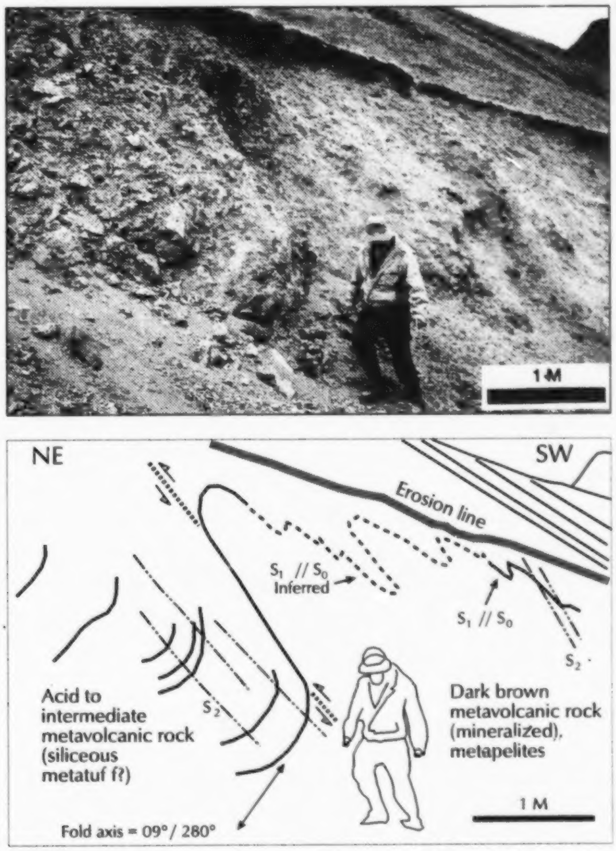

1 M
NE
SW
Erosion line
S_1 // S_0 Inferred
S_1 // S_0
S_2
S_2
Acid to intermediate metavolcanic rock (siliceous metatuf f?)
Dark brown metavolcanic rock (mineralized), metapelites
1 M
Fold axis = 09° / 280°

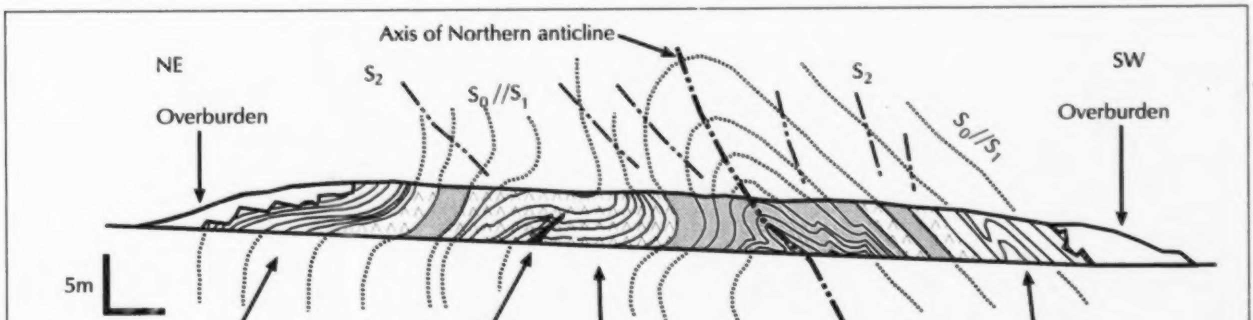
Figure 8. *Wall of exploration trench near station C, revealing folded micaceous quartzite and metapelite. Despite the advanced stage of physical weathering, structural analysis resolved F_2 folds (up to 10-m-scale) with asymmetric geometry and overturned limbs, possibly associated with south-dipping thrust faults. The attitudes of $S_1//S_0$ and S_2 measured in the limb of the southernmost fold are respectively 215°/42° and 210°/52°. The axis of the major fold is 09°/280°.*

penetrative and anisotropy of $S_0/S_1/S_2$ planes. These planes dip southerly at moderate to high angles.

The structures of the first two events define a sub-horizontal, north-northeast-trending maximum compressive stress, with a sub-horizontal intermediate stress parallel to the east-southeast-trending fold axis of the F_1 and F_2 folds (Fig. 7 and stereonets in D'el-Rey Silva et al., Part I; this volume). The D_3 event is characterized by open to tight, generally <1-m-scale, kink-style F_3 folds, and by a penetrative foliation (S_3) that dips steeply and cross cuts $S_0/S_1/S_2$ planes. These D_3 structures are the plane of intermediate stress (commonly to west-northwest; Fig. 7d); another set of fractures, planes and spaced cleavage (S_{3a}, Fig. 7e) dips shallowly and generally northward and defines the plane of minimal compressive stress. As a whole, the D_1-D_3 evolution appears to be progressive, and suggests a single tectonic cycle.

Two localities of continuous exposure, as well as the spatial relationship between the S_2 foliation with the S_0/S_1 planes, and asymmetry of m- to dm-scale parasitic F_2 folds, demonstrate the existence of two larger F_2 anticlines. These are termed Northern and Southern anticlines in Figure 5. The upright limbs of these F_2 folds dip 30° to 55° south-southwest, whereas the overturned limbs dip between 70° to 85° south-southwest. Definition of these major folds permit inference of an intervening overturned F_2 syncline, shown in the vertical cross section (Fig. 4b). These structures are described in detail as follows.

Figure 9. *Sketch of the eastern wall of the trench near C (Figure 8 is from slightly left of centre), illustrating the sequence of mineralized metavolcanic layers (shaded).*


Axis of Northern anticline
NE
SW
S_2
$S_0//S_1$
S_2
$S_0//S_1$
Overburden
Overburden
5m
5m
Intermediate siliceous unit
Quartz-feldspar pegmatite
Well banded siliceous metatuff
Intermediate siliceous unit

THE NORTHERN ANTICLINE

The Northern anticline, nearly 1 km wide, is defined in the northeastern part of the area. South of the trace of the axial plane, outcrops 3 to 9 systematically display S_2 dipping more steeply south than S_0/S_1, thus defining the normal limb. In outcrops 10 through 16 north of the axial trace, S_2 dips less than S_0/S_1, and defines the shorter limb. The hinge is well exposed along a 70-m-long, northeast-trending trench close to survey station C (Fig. 8 and 9).

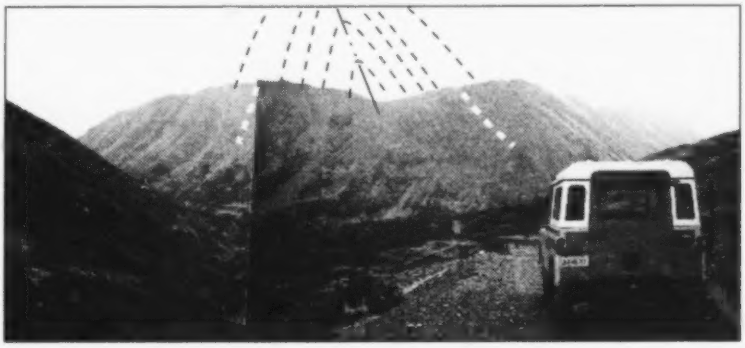


Figure 10. An eastward view of the spur containing the BOUND claims. The dashed white line marks the approximate position of the discontinuous marble layer. The general structure is interpreted as the continuation of the Northern anticline.

From outcrop 16 the overturned limb is exposed on the ridge crest that forms the northern limit of mapping. This outcrop consists of east-southeast-trending, sub-vertical siliciclastic rocks. Eastward, the ridge crest turns to the south and trends across the strike of different rock units (outcrops 59 to 52). The hinge of the Northern anticline (see Fig. 5a) passes through the 120-m-wide marble unit (outcrops 59, 58 and 57). The hinge is preserved by the ridge topography; on the east-facing slope this marble unit extends as two separate limbs.

The marble layer is exposed along the overturned limb of the Northern anticline as

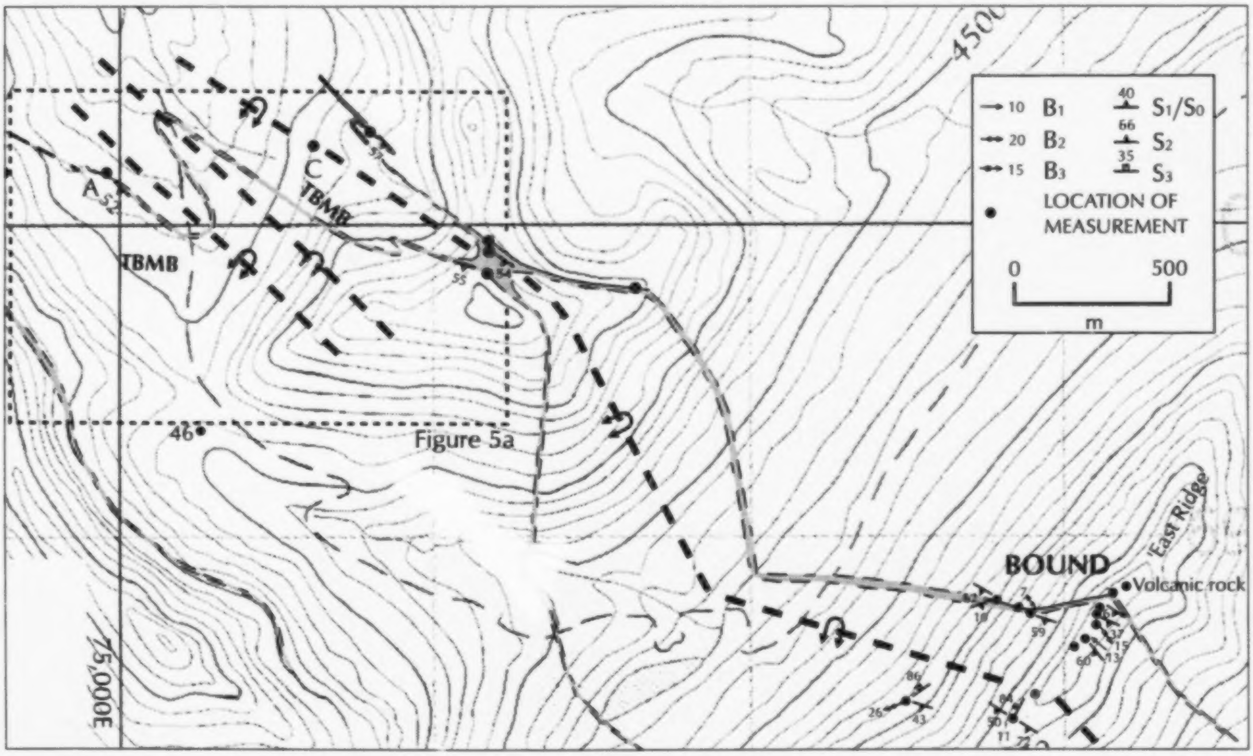


Figure 11. Simplified map of the area enclosing the TBMB and BOUND claims. The marble layer (shaded) indicates the position of the F_2 folds. Bends in the marble layer in valleys reflect use of the "rule of V's" for dipping planar structures (Ragan, 1985).

well, particularly to the east of trench C. Outcrops 38 and 39 contain beautiful examples of isoclinal F_1 folds (Fig. 6). The angular relationships between the S_2 foliation and the previous planar structures reveal a 10-m-scale anticline-syncline pair (outcrops 38 and 39) that are parasite folds on the overturned limb of the Northern anticline.

THE SOUTHERN ANTICLINE

This is a nearly 500-m-wide structure defined along a succession of outcrops in the northwestern border of the area (numbers 26, 25, 25A, 37, 36, 35, 32, 34, and 33; see Fig. 5a). The fold hinge is outlined by a nearly 200-m-long exposure of >1-m-thick layers of sericite-quartz schist and sericite quartzite along a northeast-flowing creek between outcrops 37 and 33. The layers display well-defined composite banding (S_0/S_1) with several cm- to dm-scale intrafolial F_1 folds. The upright, southern limb of the Southern anticline (defined between outcrops 37 and 26) encloses a layer of marble (outcrop 25A) along strike with a marble layer mapped east-southeast in trench A (outcrop 31).

LITHOSTRATIGRAPHY

The lithostratigraphy of the area was determined after the definition of the Northern and Southern anticlines. It consists of five units (Fig. 5a): Lower, Intermediate and Upper siliciclastic units (respectively LU, IU, UU), separated by metavolcanic and marble units (respectively VU and UM). Tracing the marble marker horizon around the hinge of the Southern anticline and through the intervening syncline, one reaches the hinge of the Northern anticline at the eastern part of the area (outcrop 57; see Fig. 5a). The metavolcanic rocks also turn around the hinge of the Northern anticline, but are structurally lower than the marble. The formlines for the VU unit respect the scale of the folds and the attitudes measured along the normal limb of the Northern anticline (outcrops 3-11 and 17-24). These two marker units permit division of the siliciclastic rocks into three units, as shown in the vertical cross-section (Fig. 5b).

STRUCTURE NEAR THE BOUND CLAIM

The same rock types are present 3 km southeast of the TBMB area, and similar D_1-D_3 structures are evident. The east-southeast-trending layers cross a ridge spur containing a discontinuously exposed marble horizon (Fig. 10). The angular relationships between S_2 and S_0/S_1 along the crest indicate that the southern part of the ridge corresponds to the longer upright limb of an anticline, whereas the northern part of the crest, in which the layers are sub-vertical, corresponds to the shorter limb. The authors interpret this structure as a major overturned F_2 anticline that is the eastern continuation of the Northern anticline (Fig. 11).

CONCLUSIONS

The mapping and structural analysis of the TBMB area has shown that the scattered, isolated outcrops of marble constitute a marker horizon within a coherent stratigraphic succession. Furthermore, the overturned anticline defined by this stratigraphy continues at least 3 km to the east. This detailed work therefore extends the possibility that a general stratigraphy can be worked out, at least on the scale of a single mountain, where distinct marker horizons are present. This is profoundly important to the search for stratiform sulphide mineralization. At the trench near survey station A, 12% Zn has been sampled, and sphalerite is also found in the trench near station C.

There is little doubt that the structures mapped in the TBMB area are related to those of the Dan area; the same deformation phases and structural style are present at both. Clearly the entire region underwent many of the same deformational events.

Could all these rocks have the same protolith? The first and second authors have examined both areas and propose that rocks of the TBMB area are part of the Ram Creek assemblage. The proposition that the Ram Creek assemblage extends as far south as TBMB requires that the belt of Dorsey rocks (Stevens and Harms, 1995; 2000) between the two localities is either not exposed or tightly infolded. The former is more likely, because on the regional scale a south-dipping thrust brings Dorsey assemblage rocks over top of the Ram Creek assemblage. This problem cannot be resolved until the intervening ridge (north of the TBMB and south of the Atom showings) has been examined, and this is planned for 2001.

Another intriguing possibility is that the marble exposed at the TBMB and Bound showings corresponds to the large limestone outcrops about 4 km further east (area shown on Fig 2; illustrated in Fig. 12 of Roots et al., 2000). The marble at the latter locality is thicker (varies from 20 to 50 m) than at the TBMB (2-10 m) and appears to be less deformed; it contains unidentified crinoids and other organic debris, and includes carbonate blocks in darker phyllite near its structural base (Roots et al., 2000). To resolve this, the stratigraphic sequences must be described for both areas, and outcrops flanking the kilometre-wide valley separating this area from the spur containing the BOUND claim warrant careful examination.

ACKNOWLEDGEMENTS

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Felsic metavolcanic rocks at Matt Berry: A new deposit model

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ABSTRACT

Exhalative Pb-Zn-Cu mineralization of the Matt Berry deposit is hosted in polydeformed black shale that is underlain by a strongly deformed felsic schist. The copper-rich nature of the ore, volcanic textures in the ore contacts, and the presence of alkaline felsic metavolcanic rocks beneath the deposit, suggest that the mineralization fits a mineral deposit model intermediate between sedimentary exhalative (SEDEX) and volcanogenic massive sulphide (VMS) end members.

RÉSUMÉ

La minéralisation de plomb-zinc-cuivre du gisement de Matt Berry est logée dans un shale noir polydéformé qui repose sur un schiste felsique fortement déformé. La forte teneur en cuivre du gisement, les textures volcaniques aux contacts de minerai, et la présence de roches métavolcaniques felsiques alcalines sous le gisement, indiquent que la minéralisation correspond a un modèle de gisement minéral intermédiaire entre un gisement sédimentaire exhalatif et un gisement de sulfure massif volcanogène.

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INTRODUCTION

During the 2000 field season, YTG Mineral Resources Branch carried out fieldwork in order to refine the mineral deposit models applicable to the western part of Selwyn Basin in Frances Lake map area (105H; Fig. 1). The Matt Berry deposit, Maxi prospect and the Simpson Tower area, were the principal areas of study of sedimentary exhalative (SEDEX)-type mineralization. Geological work involved mapping at 1:10 000 (Matt Berry), 1:20 000 (Simpson Tower), and 1:50 000 (Maxi) scales, as well as field checks at 1:250 000 scale (Nipple Mountain and Cenozoic basalts). Collection of samples for geochemical analyses, radiometric analyses (Pb-Pb and U-Pb), conodont dating, and petrographic studies were also conducted.

LOCATION AND ACCESS

The Matt Berry deposit is located on the northeastern shore of the East Arm of Frances Lake (Fig. 2). Access is by float plane from Finlayson or McEvoy lakes, or by boat

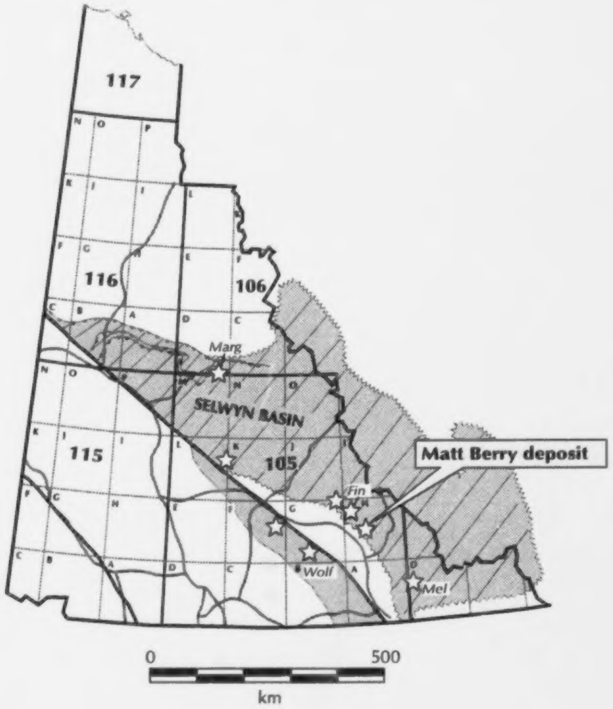
117
116
106
115
105
SELWYN BASIN
Marg
Fin
Wolf
Mel
Matt Berry deposit
0
500
km

Figure 1. Location map of Matt Berry deposit. Occurrences of felsic volcanic rocks (indicated by stars) in Devono-Mississippian strata of western Selwyn Basin and Cassiar Terrane (shaded).

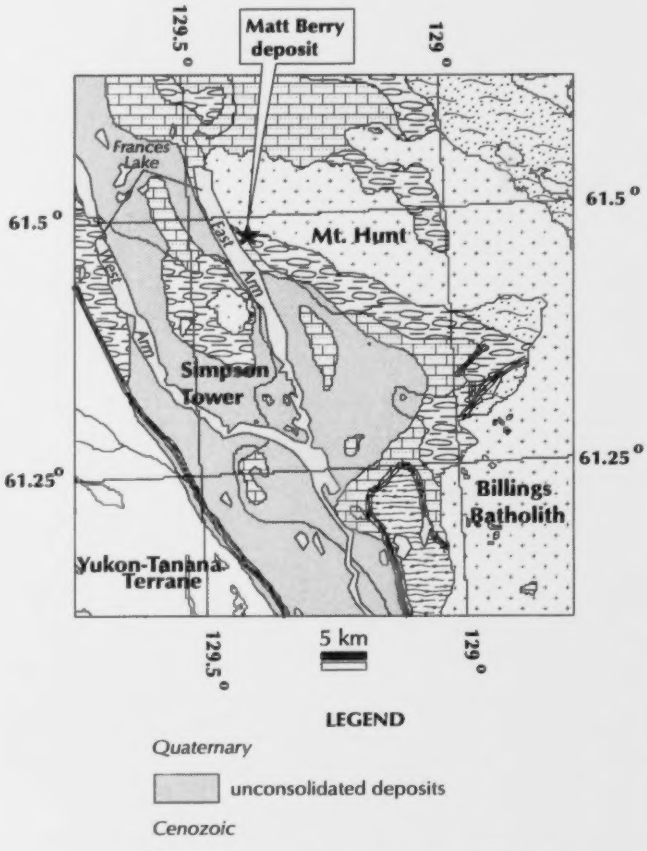
Matt Berry deposit
129.5°
129°
61.5°
61.25°
Frances Lake
West Arm
East Arm
Mt. Hunt
Simpson Tower
Billings Batholith
Yukon-Tanana Terrane
5 km
LEGEND
Quaternary
unconsolidated deposits
Cenozoic
basalt and gabbroic flows, uncertain age
Mid-Cretaceous Tay River plutonic suite
medium- to coarse-grained granite
SELWYN BASIN
Middle Devonian to early Mississippian Earn Group
black shale and conglomerate
Silurian to Devonian McEvoy platform
sandstone, limestone, shale
Late Proterozoic to Early Cambrian Hyland Group
grit, shale, sandstone
YUKON-TANANA TERRANE
Mid- to late Paleozoic
metavolcanic, metaplutonic, and metasedimentary rocks

Figure 2. Regional geology of central Frances Lake area (modified from Gordey and Makepeace, 1999).

(approximately 60 km) from the Frances Lake campground. Remains of an old exploration camp are located at the mouth of Thompson Creek, immediately northwest of the deposit.

REGIONAL GEOLOGY AND MINERALIZATION OF FRANCES LAKE AREA

Frances Lake map sheet (105H) was mapped at 1:250 000 scale by Blusson (1965). Gordey and Makepeace (1999) compiled and further interpreted the geology of Frances Lake area (Fig. 2).

The area of study is located at the western edge of Selwyn Basin, where siliciclastic and carbonate deposition took place under different tectonic environments, from Late Proterozoic through Triassic time. Throughout its existence, four main extensional (rift) events have been documented. These extensional events produced down-dropped blocks, localized volcanism, SEDEX mineralization on and near the seafloor, and deeply penetrating normal faults that were reactivated throughout the geological history of Selwyn Basin.

Siluro-Devonian limestone, calcareous shale, and possibly quartz-arenite are interpreted as McEvoy Platform – a high-standing block to the west of Selwyn Basin (Gordey and Makepeace, 1999). McEvoy Platform may represent an eastern-most, autochthonous part of Cassiar Platform.

Mesozoic deformation started in Permo-Triassic time, and ended before the emplacement of mid-Cretaceous granitic batholiths and plutons. The timing of emplacement of eastern Yukon-Tanana Terrane (Finlayson Lake district) onto Selwyn Basin is pre-Triassic. Cenozoic strike-slip movement along Tintina Fault juxtaposed metamorphic rocks of Yukon-Tanana Terrane (Finlayson Lake district) to those of Cassiar Platform, and Selwyn Basin to Cassiar Platform and Yukon-Tanana rocks. Cenozoic magmatism produced basaltic rocks that crop out in the southern Frances Lake map area.

MATT BERRY DEPOSIT

The Matt Berry deposit is an unusually copper-rich, small tonnage SEDEX deposit (105H 021, Yukon MINFILE, 1997). Calculated reserves are 533,434 tonnes grading 6.1% Pb, 4.8% Zn, and 102.9 g/t Ag. Copper grades are not quoted in the reserves.

Work history

Galena-sphalerite-rich float in the Thompson Creek area was first reported by Dawson (1887). The area was first staked in 1944. Between 1966 and 1969, Matt Berry Mines Limited carried out trenching and EM surveys, and drilled 29 holes (2298 m). Between 1970 and 1971, the property was under option by Inco and Metallgesellschaft (now Inmet), who drilled 4 holes (426.7 m). In 1974, Anvil Mining Corporation conducted soil sampling and geophysical surveys (ground magnetics and gravity). In 1978, Welcome North Mines Limited conducted a pulse-EM survey. In 1979, Sovereign Metals Corporation, in a joint venture with Cominco, conducted trenching, geological mapping, geochemical surveys, and drilled 5 holes (1229 m). Sovereign changed name to Barytex Resources, which currently owns the claims. Pulse Resources optioned the property in 1986 and carried out the following work between 1987 and 1991: magnetic and geochemical surveys followed by staking of the BETH claims (1987); cutting and staking the BINTI claims (1988); geological mapping, soil sampling and geophysical surveys (1989); and drilling contracted to Pamicon Consultants (four diamond-drill holes, 303 m, 1991). After Pulse Resources dropped the option, Barytex Resources Corporation cut 53 km of line (1993), and staked the PAT claims (1994), which have since lapsed.

Geology and mineralization

The Matt Berry deposit is located in a densely vegetated area, where outcrops are rare and restricted to riverbanks or the shore of Frances Lake. Stratigraphic and structural relations to shallower water facies to the south and northwest are poorly defined. Two Pb-Pb analyses of galena from the Matt Berry deposit were used to constrain the 'Shale Curve' of Godwin and Sinclair (1982) and yielded a Devonian age, suggesting that the black shales hosting the mineralization are coeval with Earn Group rocks.

The area is underlain by dark grey to black phyllite, which is the host to mineralization. A trench exposes a 45-cm-thick massive sulphide layer on the south shore of Thompson Creek (Fig. 3). The sulphide bed consists of mainly galena, sphalerite and quartz, with lesser chalcopyrite and bornite, hosted in dark grey to black phyllite to carbonaceous phyllite. Mineralization thickens and is open to the east. Sulphide-bearing quartz veins, up to 1 m thick, crosscut carbonaceous phyllites to the south of the deposit along the eastern shore of Frances Lake.

An examination of drill core from Pulse Resources' 1991 exploration program revealed dark phyllites in the footwall of the Matt Berry zone which are underlain by a strongly deformed, quartz-sericite augen schist (Fig. 4). Abundant angular quartz grains, and quartz and muscovite replacing feldspar prisms in thin section, suggest a felsic volcanic protolith for the schist (Figs. 5 and 6). Small outcrops of the felsic schist were reported by Cominco geologists south of the Matt Berry camp, and above treeline on the Simpson Tower. Efforts to locate these outcrops during the 2000 field season were unsuccessful.

Geochemistry of samples from drill core (Table 1) indicates that these rocks are trachytic in composition (Fig. 7a). Trace element discriminants suggest that they formed in a within-plate setting such as an intracontinental rift (Fig. 7b). Less deformed felsic volcanic rocks in Earn Group are reported 30 km to the northwest, in Cominco's Quest and Fin SEDEX prospects (D. Rhodes, pers. comm., 2000).

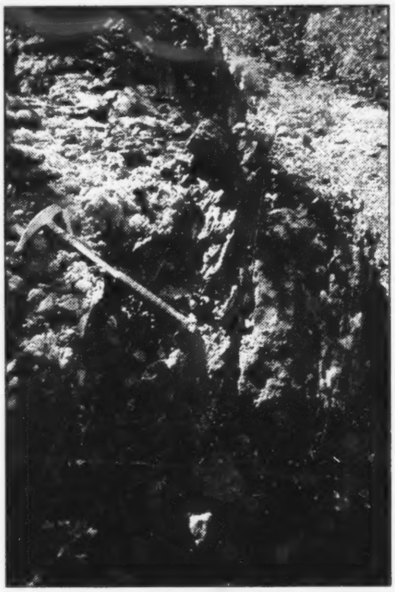

Figure 3. *Photo of the Matt Berry showing. Galena-sphalerite-chalcopyrite mineralization exposed in a trench.*

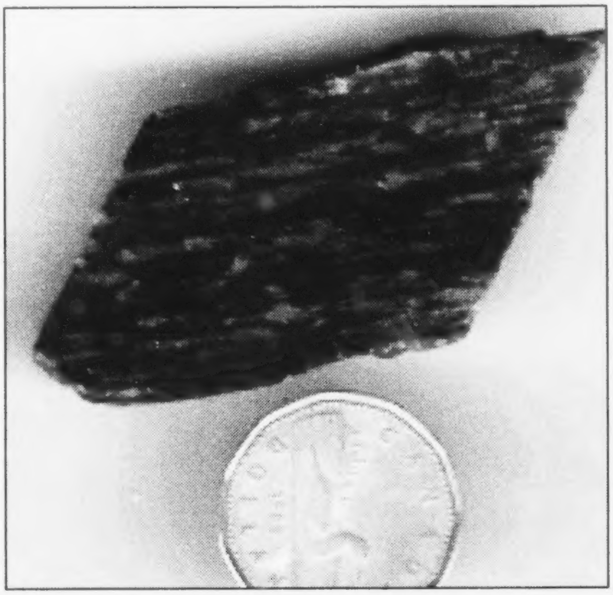

Figure 4. *Strongly deformed quartz-sericite augen schist from drill core at the Matt Berry zone.*

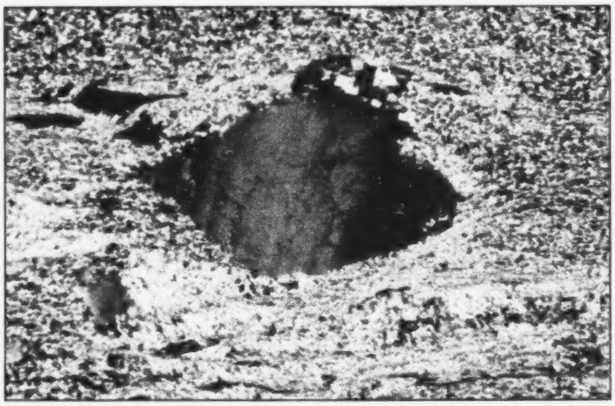

Figure 5. *Thin section of angular quartz eye in felsic metavolcanic unit. Field of view = 7.2 mm.*

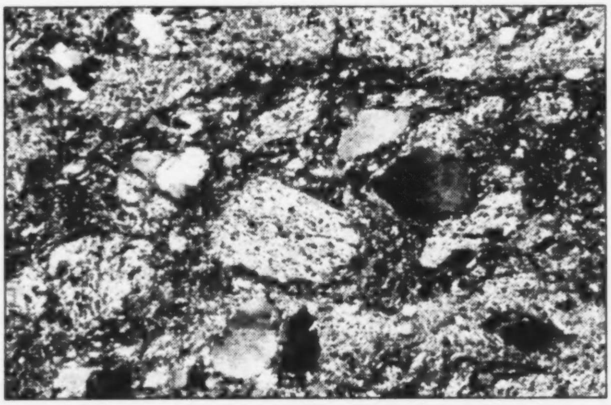

Figure 6. *Quartz and sericite replacing elongate feldspar grains in felsic metavolcanic unit. Field of view = 7.2 mm.*

SAMPLE	MB91-1-67	MB91-3-78.6	MB91-4-74.2
unit	MB	MB	MB
SiO_2	78.86	77.85	78.46
Al_2O_3	11.90	12.00	12.22
Fe_2O_3	1.52	2.70	1.79
MnO	0.006	0.065	0.070
MgO	0.44	0.94	0.53
CaO	0.04	0.11	0.29
Na_2O	0.17	0.16	0.10
K_2O	3.56	3.07	3.75
TiO_2	0.256	0.172	0.153
P_2O_5	0.04	0.04	0.02
LOI	2.04	2.06	2.05
TOTAL	98.82	99.15	99.43
V	7	9	-5
Cr	-20	-20	-20
Co	1	2	1
Ni	-20	-20	-20
Cu	26	-10	-10
Zn	737	80	42
Ga	25	23	28
Ge	1.2	1.4	1.3
As	1,200	7	221
Rb	203	166	210
Sr	15	22	19
Y	35.9	52.4	42.2
Zr	222	157	172
Nb	116	85.6	129
Mo	5	6	5
Ag	-0.5	-0.5	-0.5
In	0.6	0.3	-0.1
Sn	18	6	6
Sb	14.5	5.4	4.6
Cs	2.4	3.8	3.1
Ba	162	183	82
Hf	9.6	7.6	8.2
Ta	11.2	11.2	13.2
W	6.9	4.9	4.9
Tl	0.85	0.98	1.23
Pb	8	13	64
Bi	4.4	0.5	2.0
Th	36.9	32.3	45.6
U	5.28	8.44	12.5
La	106	57.4	83.8
Ce	208	106	172
Pr	22.9	11.0	19.1
Nd	81.6	38.2	69.1
Sm	13.3	6.53	12.2
Eu	1.60	1.37	1.11
Gd	10.0	6.83	9.40
Tb	1.47	1.48	1.47
Dy	7.57	8.91	7.98
Ho	1.42	1.71	1.49
Er	4.14	5.03	4.40
Tm	0.620	0.743	0.654
Yb	3.76	4.57	4.12
Lu	0.500	0.626	0.554

Table 1. *Major element XRF, trace element and REE ICP-MS analyses of drill core samples of quartz-sericite schist.*

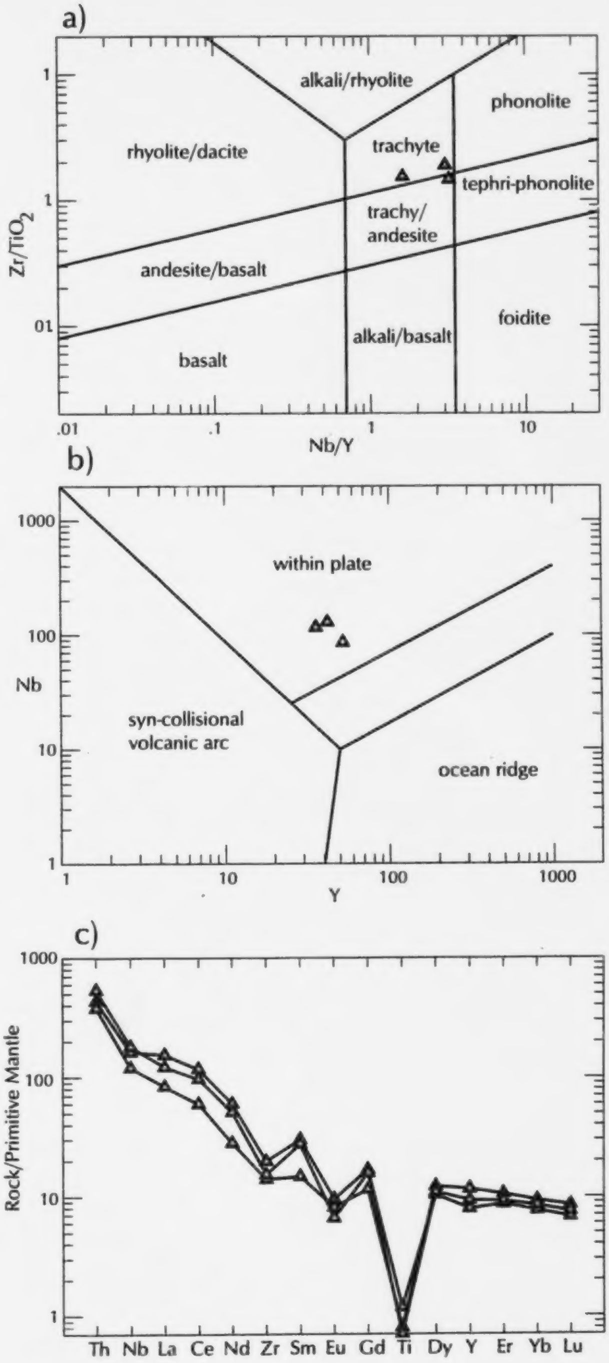

Figure 7. *(a) Zr/Ti – Nb/Y diagram of Winchester and Floyd (1977) as modified by Pearce (1996). (b) Nb-Y discriminant diagram of Pearce et al. (1984). (c) Primitive mantle-normalized incompatible element diagram. Primitive mantle values of Sun and McDonough (1989).*

Structural geology

Three foliations are observed in outcrop (Fig. 8), suggesting that three phases of deformation affected the deposit. Northeast-oriented cross-sections (Fig. 9) show the interpreted geology of the deposit. The felsic volcanic unit consistently underlies the mineralization, but the distance between mineralization and the volcanic unit varies from 23 m to over 75 m. Easterly to east-northeasterly directed thrusting and folding brings the mineralized sequence closer to surface towards the east. The variable thickness of low-grade to barren phyllite between the quartz-eye felsic volcanic unit and the mineralization is interpreted as the result of folding along an approximate east axis. This interpretation implies repetition of the mineralization at greater depth, and is in line with structural observations recorded in the area. Alternatively, this variation in thickness may result from a combination of transposition of bedding and variable distance to the volcanic centres.

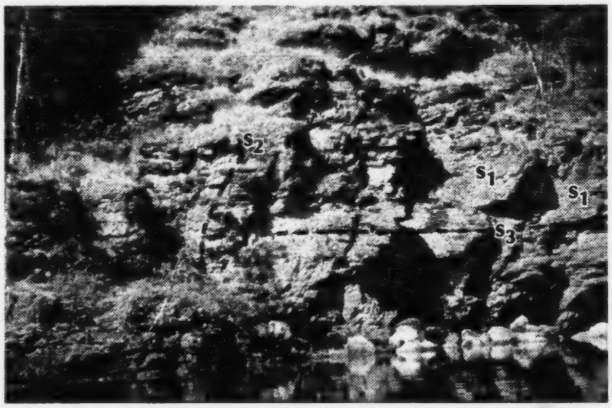

Figure 8. *Outcrop along shoreline of East Arm of Frances Lake, south of Matt Berry deposit. First phase foliation (S_1) is parallel to the photograph. Second phase foliation (S_2) is folded and steeply dipping. Third phase foliation (S_3) is sub-horizontal and sub-parallel to bedding.*

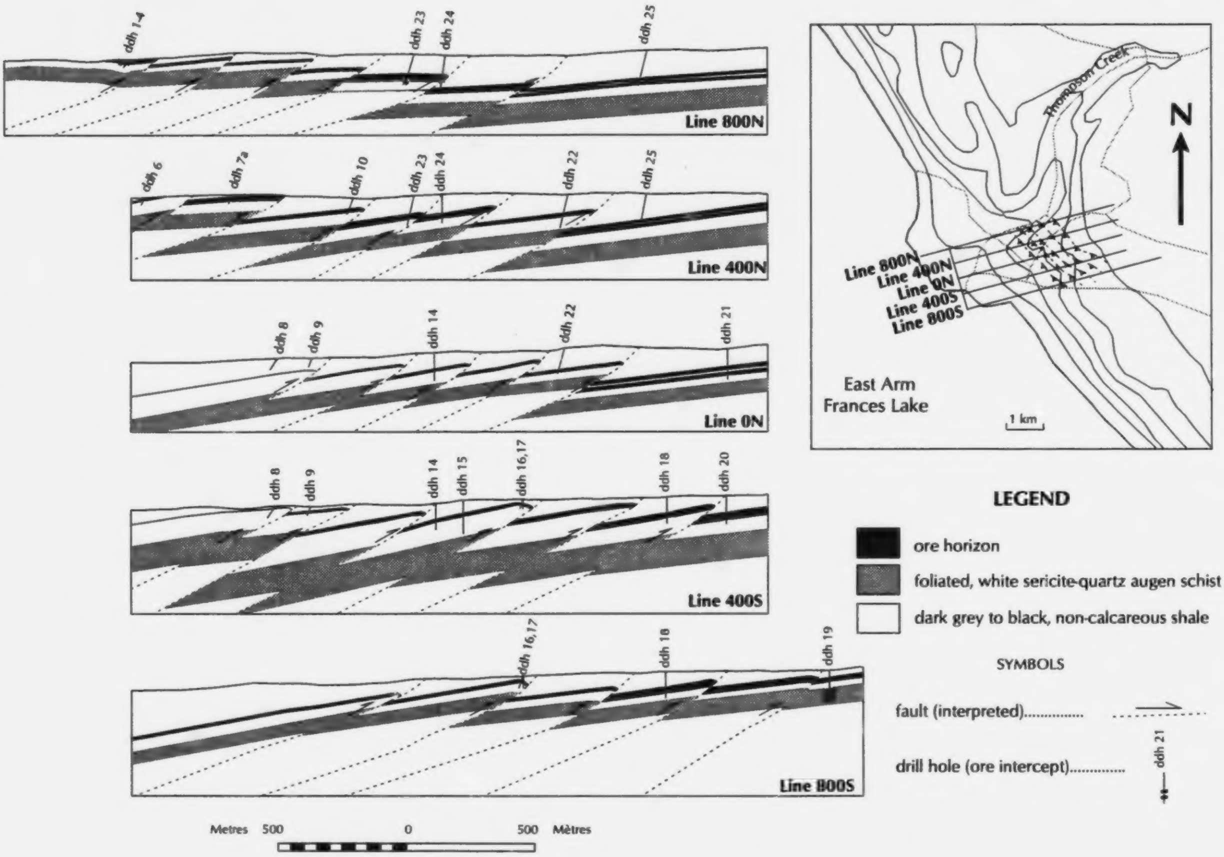
ddh 1-4
ddh 23
ddh 24
ddh 25
Line 800N
ddh 6
ddh 7a
ddh 10
ddh 23
ddh 24
ddh 22
ddh 25
Line 400N
ddh 8
ddh 9
ddh 14
ddh 22
ddh 21
Line 0N
ddh 8
ddh 9
ddh 14
ddh 15
ddh 16,17
ddh 18
ddh 20
Line 400S
ddh 16,17
ddh 18
ddh 19
Line 800S
Metres 500
0
500 Mètres
Thompson Creek
N
Line 800N
Line 400N
Line 0N
Line 400S
Line 800S
East Arm
Frances Lake
1 km
LEGEND
ore horizon
foliated, white sericite-quartz augen schist
dark grey to black, non-calcareous shale
SYMBOLS
fault (interpreted)..............
drill hole (ore intercept)..............
ddh 21

Figure 9. *Northeast cross-sections of the Matt Berry deposit (looking northwest, 400 m spacing, no vertical exaggeration) displaying interpreted easterly directed thrusting and folding, and a felsic volcanic unit underlying the mineralization.*

Ore petrography

A reflected light petrographic study of mineralization from the Matt Berry showing demonstrated the copper-rich nature of the deposit. Locally, chalcopyrite makes up to 2% of the rock volume. Typical paragenesis in the showing is: quartz → sphalerite → quartz, chalcopyrite, pyrite → galena → covelite, marcasite, quartz, sericite (Fig. 10). Chalcopyrite also occurs as exsolutions in sphalerite and is concentrated as fine-grained crystals along the contacts with unmineralized phyllite. Angular quartz eyes along the contacts of the mineralization suggest a volcaniclastic component to the mineralization (Fig. 11). Principal gangue minerals are quartz, carbonate, and sericite.

Deposit model

The presence of alkaline felsic volcanic rocks underlying mineralization, unusually high copper grades, small tonnage, and volcanic textures along the ore-wallrock contacts, demonstrate a strong volcanogenic component in the Matt Berry deposit. Intensely deformed quartz-eye schist underlying the mineralization resembles felsic metavolcanic rocks of Yukon-Tanana Terrane, or rocks in the Tombstone strain zone of Selwyn Basin.

The possibility that the Matt Berry deposit lies in Yukon-Tanana Terrane rocks was examined and rejected in the course of this research project. Rocks in the Simpson Tower area to the west, are dark grey chert-pebble conglomerate, sandstone and hornfelsed shale that do not show the same amount of strain as the quartz-eye schist underlying the Matt Berry ore, and are interpreted as Earn Group. The possibility that the Matt Berry deposit lies on a klippe of Yukon-Tanana Terrane, which is the northerly extension of greenstones mapped by Blusson (1965) and interpreted by Gordey and Makepeace (1999) as a klippe of Slide Mountain Terrane affinity, was also rejected. An examination of rocks from the greenstone unit showed that they are undeformed (recent and autochthonous) basaltic flows.

CONCLUSIONS

The previously unreported felsic volcanic unit that underlies the Matt Berry deposit may represent a significant metallogenic district in western Selwyn Basin. Occurrences of felsic volcanic rocks of Devono-Mississippian age are known from many localities in western Selwyn Basin (Fig. 1). Base-metal prospects are associated with many of the known occurrences of felsic rocks (e.g., Fin and Quest properties, Mel property and Marg deposit; see also Holbek et al., this volume). Other occurrences, such as felsic volcanic rocks in Earn Group of northeastern Glenlyon area (105L; Gordey and Makepeace, 1999), remain uninvestigated.

A strong volcanogenic component was observed in the host rock geology and ore contacts of the Matt Berry deposit, suggesting that the mineralization represents a hybrid mineral deposit type, which has characteristics of sedimentary-exhalative (SEDEX)- and volcanogenic massive sulphide (VMS)- type mineralization. Hybrid deposits of this type are more Cu- and possibly Au-rich

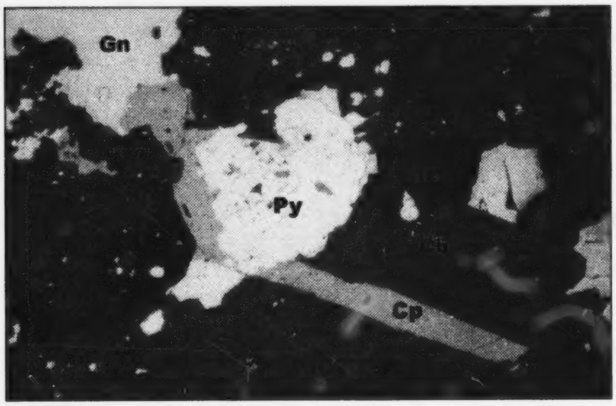

***Figure 10.** Large chalcopyrite crystal interstitial to pyrite, carbonate, quartz, and sphalerite. Gn = galena; Py = pyrite; Qz = quartz; Cb = carbonate; Cp = chalcopyrite. Field of view = 1.75 mm.*

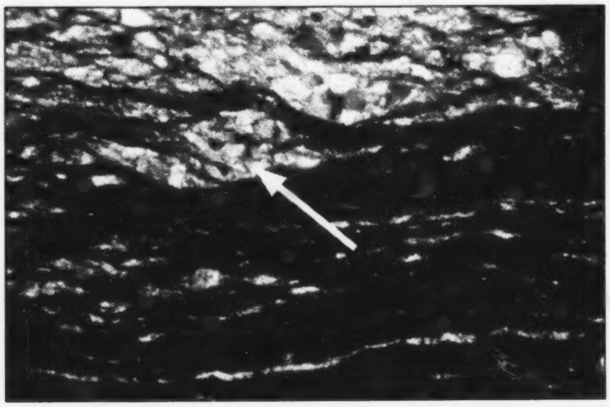

***Figure 11.** Angular quartz along the contacts of the Matt Berry ore zone. Field of view = 7.2 mm.*

than those developed in more typical SEDEX environments. Proposed Pb-Pb analyses of galena in the mineralization and of pyrite in the volcanic unit will show conclusively whether or not there is a genetic relation between the extrusion of felsic volcanic rocks and mineralization.

ACKNOWLEDGEMENTS

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Structure and stratigraphy of the Marg volcanogenic massive sulphide deposit, north-central Yukon

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ABSTRACT

The Marg (Cu-Zn-Pb-Au-Ag) volcanogenic massive sulphide deposit is hosted within metasedimentary and metavolcanic rocks of the Devonian–Mississippian Earn Group and Mississippian Keno Hill Quartzite. These rocks form part of the Selwyn Basin, an off-shelf sequence that developed at the continental margin prior to Cordilleran deformation and accretion.

Geological mapping and re-analysis of drill core was completed to re-assess the deposit and property-scale economic potential. The Marg deposit is deformed by at least three generations of structures that developed during Late Jurassic to Early Cretaceous time and are geometrically correlative with regional-scale structures such as the Robert Service Thrust and the Tombstone strain zone. The Marg deposit occurs within a southeasterly plunging, complex fold structure, a significant part of which has been removed by erosion. Discovery of additional stratigraphy comparable to the Marg sequence and new sulphide occurrences within the claims underscores both property and regional exploration potential. The presence of probable rift-related volcanism and mineralization within the Selwyn Basin, and the similarities of this mineralization to that within 'suspect' terranes, has implications for both regional tectonics and exploration.

RÉSUMÉ

Le gisement de sulfure massif volcanogénique (Cu-Zn-Pb-Au-Ag) de Marg est logé dans les roches métasédimentaires et métavolcaniques du Groupe d'Earn, d'âge Dévonien–Mississippien, et dans le Quartzite de Keno Hill, d'âge Mississippien. Ces roches font partie du Bassin de Selwyn, une séquence de talus qui s'est développée le long de la marge continentale avant le stade de déformation et d'accrétion de la Cordillère.

On a établi une carte géologique et analysé de nouveau les carottes de forage afin de réévaluer le potentiel économique du gisement et de l'ensemble de la propriété. Le gisement de Marg fut déformé par au moins trois générations de structures qui se sont succédées du Jurassique tardif au Crétacé précoce et sont en corrélation géométrique avec les structures régionales telles le Chevauchement de Robert Service, la zone déformée de Tombstone, et l'antiforme de Mayo. Le gisement de Marg repose dans une structure complexe de plis qui plongent vers le sud-est et dont une proportion importante a été effacée par l'érosion. La découverte d'autres unités stratigraphiques comparables à la séquence de Marg et de nouveaux indices de sulfures sur les claims révèle le potentiel d'exploration régionale. Les indices de volcanisme et de minéralisation dans le Bassin de Selwyn, qui sont probablement reliés à l'extension régionale, de même que les similitudes entre cette minéralisation et celle des terranes 'suspects', ont une influence à la fois sur la tectonique et l'exploration régionales.

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INTRODUCTION

The Marg volcanogenic massive sulphide deposit is hosted within a thick sequence of predominately metasedimentary rocks of the North American continental margin and, as such, represents an unusual setting for this deposit type. The deposit currently has a resource of 5.5 million tonnes grading 1.76% Cu, 4.5% Zn, 2.5% Pb, 86 g/t Ag and 0.9 g/t Au (Franzen, 1997). Recent geological work described herein suggests that the original deposit was substantially larger prior to erosion, demonstrating that the deposit type is an attractive exploration target. Exploration work during the 2000 field season consisted of geological mapping (1:5000 scale), geochemical sampling, prospecting, and re-logging drill core, plus geochemical analysis of previously drilled core. The purpose of this work was to better understand the geological setting, stratigraphy and structure of the deposit and its host rocks, as well as the geochemical changes associated with mineralization and alteration, in order to guide future exploration.

LOCATION AND ACCESS

The Marg claims are located in central Yukon on NTS map sheets 105M/15 & 16, 106D/1 & 2, centred at approximately 64°00' N and 134°30' W (Fig. 1). Access to the claim group is by helicopter from Mayo (located approximately 80 km to the southwest), or by small aircraft to a 380-m-long airstrip located near the Marg deposit area. The Marg property consists of 402 contiguous mineral claims covering approximately 8403 hectares. The property is owned by a joint venture between Atna Resources Ltd. ($66^{2}/_{3}$%) and Cameco Corporation ($33^{1}/_{3}$%).

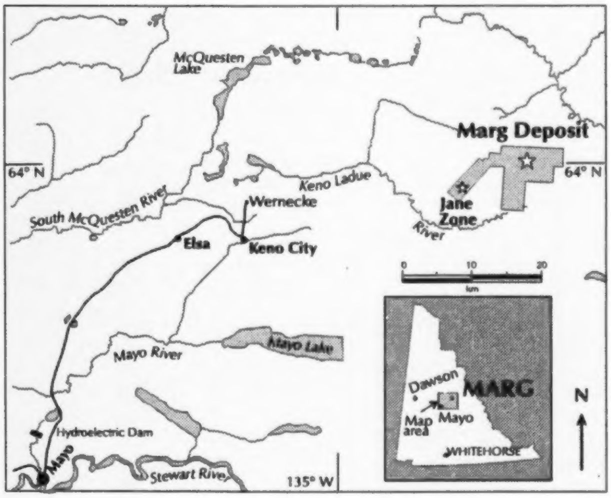


Figure 1. Location map of the Marg property, north-central Yukon.

Claims are situated within sub-alpine to alpine terrain within the Patterson Range with elevations varying from 600 to 1900 m. The majority of the claim block is covered with a thin veneer of talus or colluvium. Overall, outcrop exposure averages less than 10%, although some slopes within cirque headwalls approach 70% exposure.

EXPLORATION HISTORY

The Marg property has an extensive history with numerous owners and work programs attesting to both the difficulty of discovery, and the benefits of perseverance. Although there have been many owners, until the most recent program, all of the work carried out on the property, including its discovery, has been undertaken by Archer Cathro & Associates (1981) Ltd. and their predecessors.

The Marg area was first staked in 1965 by a joint venture between United Keno Hill Mines Ltd. and Canadian Superior Exploration Ltd. The joint venture program, following the release of the Geological Survey of Canada reconnaissance stream sediment survey results, entailed geochemistry and prospecting with the objective of finding Keno Hill-style silver veins. No significant silver mineralization was found and the claims were allowed to lapse. In 1982, the area was re-staked by the ZX joint venture between SMD Mining Company Ltd. (now Cameco), Chevron Minerals Ltd., and Enterprise Exploration Ltd. (an Australian exploration subsidiary of Rio Tinto). An exploration program included hand trenching in geochemically anomalous areas in search of sedimentary exahalative-style (SEDEX) lead-zinc mineralization. Enterprise abandoned their interest in the property and the project was optioned to All-North Resources Ltd. (All-North) who earned a 50% interest through a program that included geochemical and geophysical surveys (VLF and MaxMin EM, magnetometer, and IP) plus trenching. In 1987, NDU Resources Ltd. (NDU) purchased All-North's interest and Chevron converted its 25% working interest to a 5% net profits interest. This resulted in NDU controlling $66^{2}/_{3}$% of the joint venture and Cameco controlling $33^{1}/_{3}$% of the property.

The NDU/Cameco joint venture explored the property in two phases. NDU's portion of the second phase was financed through a short-lived option with Noranda Inc. and Brenda Mines Ltd. The 1988 work program included claim staking, geological, geochemical, and geophysical surveys (VLF and Pulse EM) plus 6038 m of diamond drilling in 33 holes, which defined extensive volcanogenic mineralization. Work also included construction of a 380-m-long airstrip, an airphoto survey, preliminary exploration of the Jane zone, and initiation of a baseline environmental program. In 1989, the NDU/Cameco joint venture continued to explore the property, and purchased Chevron's 5% net profits interest in proportion to existing ownership. Diamond drilling on the Marg zone consisted of 1819 m in five holes. Work on the Jane zone included grid geological, geochemical and geophysical (VLF-EM, Pulse EM and Magnetometer) surveys. Reconnaissance geochemical sampling was also completed over much of the property and further water samples were collected for environmental monitoring. Work continued in 1990, with an additional nine holes, totaling 4120 m, completed on the Marg zone. Hand (blast) trenching and sampling was carried out on the Jane zone. Baseline environmental monitoring surveys initiated in 1988 were continued and the resource estimate was updated.

The project was re-activated in 1996; work consisted of 8518 m of diamond drilling in 29 holes, and additional work was carried out on the Jane zone. Environmental monitoring water sample sites were re-established and sampled.

United Keno acquired NDU in 1997, thereby obtaining the majority interest in the Marg property. United Keno envisioned placing the property into production using the Keno mine site for processing the Marg ore. To this end, United Keno completed additional diamond drilling (7 holes for 2540 m) and nearly completed a winter road from the town of Keno to the property. In 1998, United Keno issued convertible debentures to Norvista Development Ltd. (Norvista) and withdrew cash through a promissory note using the Marg property as collateral. United Keno subsequently went into default on the promissory note. Norvista obtained a judgement against United Keno resulting in the court-ordered sale of United Keno's interest in the Marg claims. Atna Resources Ltd. (Atna) successfully bid on the property in late 1999. Atna and Cameco completed a novation agreement and formed a joint venture to further explore the property.

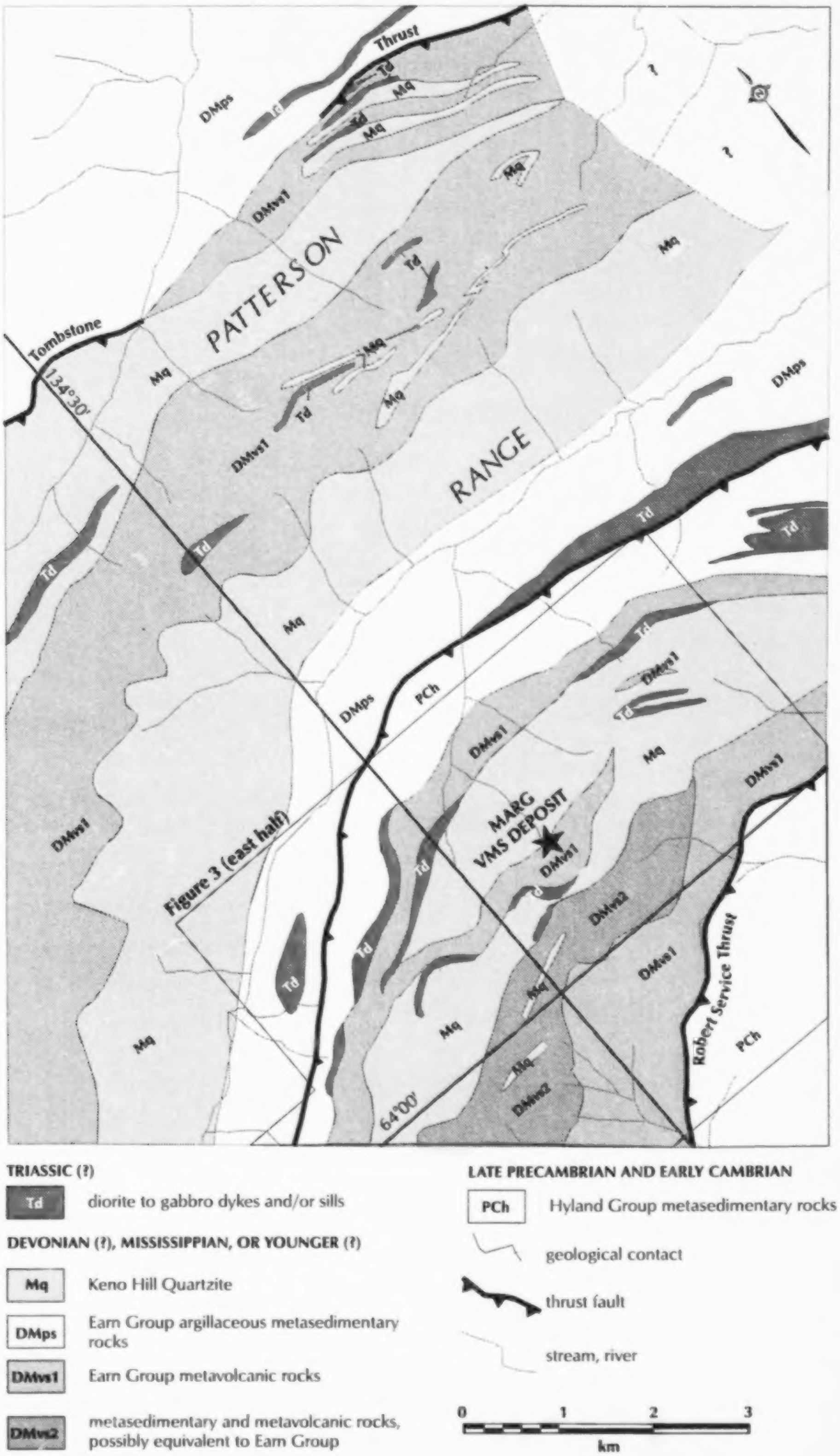
REGIONAL GEOLOGY

The Marg property lies south of a shelf/off-shelf regional boundary and within the Selwyn Basin, a predominantly off-shelf metasedimentary and metavolcanic sequence that forms part of the Foreland Belt of the northern Canadian Cordillera. Regional geology, as described by Green (1971, 1972) and Abbott (1990a,b), consists of three major tectonostratigraphic elements. These elements are, from north to south: Middle-Proterozoic shelf sequence carbonate rocks of the Wernecke Supergroup (that are unconformably overlain by Lower to Middle Paleozoic carbonate shelf sedimentary rocks); Neoproterozoic to Lower Cambrian off-shelf rocks of the Hyland Group; and Devonian to Mississippian rocks of the Earn Group and the Keno Hill Quartzite (Fig. 2). Deformation, metamorphism and imbrication of the varying stratigraphic units occurred during the Jurassic to Early Cretaceous (190 to 120 million years ago).

Three major fault structures control the geometry of the major stratigraphic units. The northern-most fault, the Dawson Thrust, separates off-shelf rocks of the Selwyn Basin (Keno Hill Quartzite, Earn Group, and Hyland Group) from shelf rocks of the Wernecke Supergroup. The central Tombstone Thrust (Fig. 2), imbricates rocks of the Keno Hill Quartzite and the Earn Group, host of the Marg deposit. The southern-most fault, the Robert Service Thrust, carries rocks of the Hyland Group onto Earn Group and Keno Hill Quartzite. The Wernecke Supergroup and other associated shelf rocks are not present in the vicinity of the Marg property and will not be discussed further.

All of the rock units have been deformed by at least two, and locally three, phases of deformation (Abbott, 1990a,b; Gordey, 1990; Turner and Abbott, 1990; Murphy, 1997). The structures are generally composed of varying degrees of ductile and brittle deformation, compatible with the lower- to middle-greenschist facies metamorphic grade of the region, and vary depending upon proximity to the thrust faults (Gordey, 1990). The first phase of deformation is characterized by north- to northeast-vergent, overturned, isoclinal folds whose axial surface parallels the south-dipping, regional-scale thrust faults (Turner and Abbott, 1990). These folds, and related thrust faults, define the major south-dipping aspect of the thrust panel, with the majority of fold axes and associated linear features plunging to the southeast. Refolding of first phase structures locally produces a penetrative rodding and mineral lineation plunging to the southeast

Figure 2. *Regional geology of the Marg property, north-central Yukon (after Turner and Abbott, 1990).*


Thrust
Tombstone
134°30'
PATTERSON
RANGE
DMps
DMvs1
DMvs2
Mq
Td
PCh
MARG
VMS DEPOSIT
Figure 3 (east half)
Robert Service Thrust
64°00'
TRIASSIC (?)
Td
diorite to gabbro dykes and/or sills
DEVONIAN (?), MISSISSIPPIAN, OR YOUNGER (?)
Mq
Keno Hill Quartzite
DMps
Earn Group argillaceous metasedimentary rocks
DMvs1
Earn Group metavolcanic rocks
DMvs2
metasedimentary and metavolcanic rocks, possibly equivalent to Earn Group
LATE PRECAMBRIAN AND EARLY CAMBRIAN
PCh
Hyland Group metasedimentary rocks
geological contact
thrust fault
stream, river
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1
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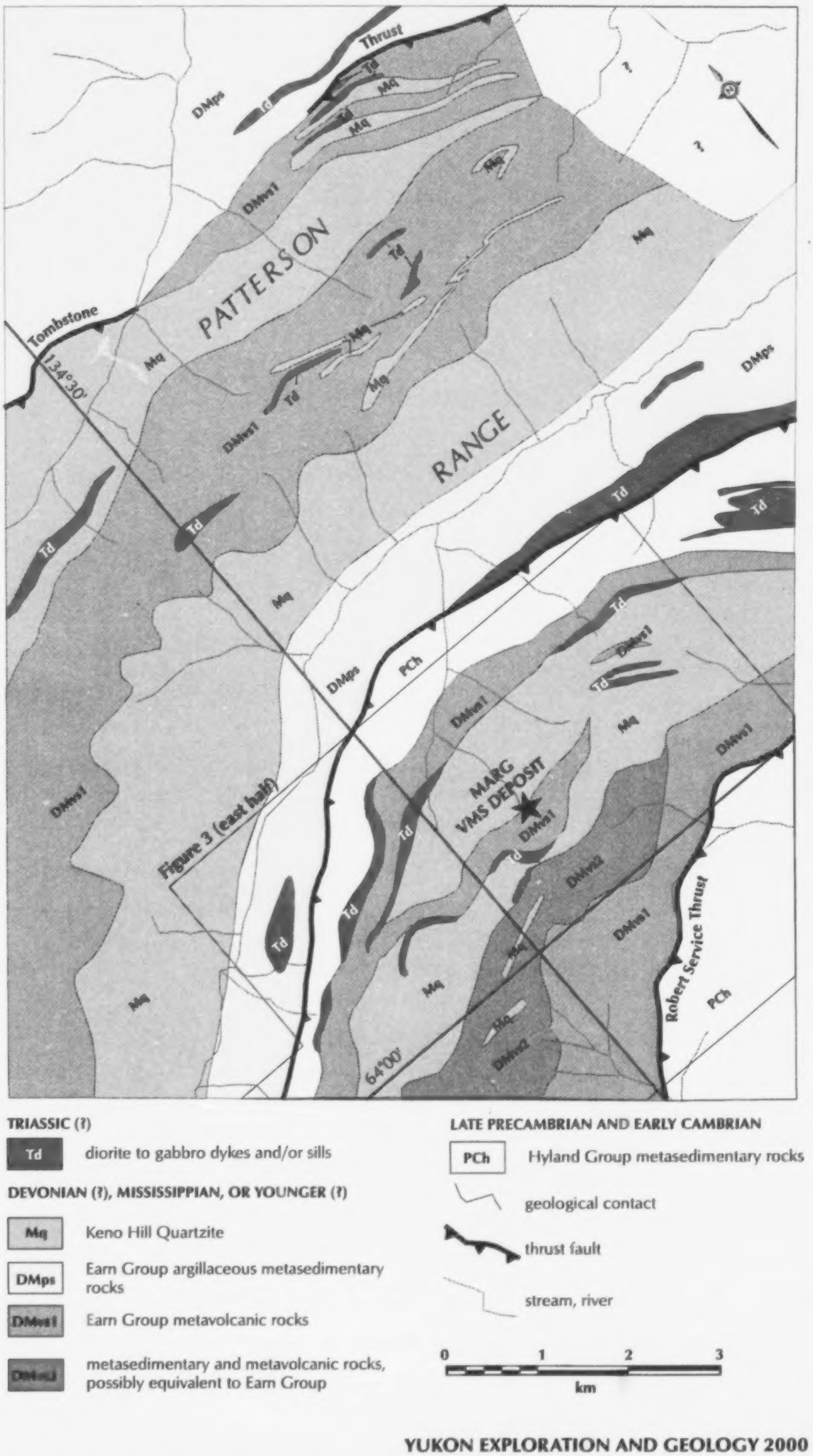
km

Figure 2. *Regional geology of the Marg property, north-central Yukon (after Turner and Abbott, 1990).*


Thrust
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DMps
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DMvs1
PATTERSON
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LATE PRECAMBRIAN AND EARLY CAMBRIAN
PCh Hyland Group metasedimentary rocks
geological contact
thrust fault
stream, river
0
1
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(Abbott, 1990a) and a second axial planar cleavage (Gordey, 1990). A later phase of deformation consists of upright, open to tight, southwest-vergent folds. These third phase folds have axial planes with steep northeasterly dips and fold axes that plunge to the south-southeast.

The two (or more) early episodes of deformation are related to shortening, imbrication, and thickening caused by overthrusting of the off-shelf and shelf sequences during a Jurassic orogeny. Elongation lineations associated with, or developed in, earlier fold structures are compatible with northwesterly motion along the thrust faults (Abbott, 1990a; Gordey, 1990), however, the northeasterly vergence of folds may also indicate earlier, northeasterly directed motion. The later generation of deformation overprints earlier structures, and may be related to re-activation along older faults.

MARG PROPERTY GEOLOGY

INTRODUCTION

Work by the Yukon Territorial Government and Federal Government in recent years has provided a new geological framework for the Marg area. In order to place the property and deposit geology within this new framework, geological mapping at 1:5000 scale, detailed core logging and evaluation of previous work was undertaken. Previous workers classified and described stratigraphy using metamorphic mineral assemblages. Although the rocks are highly strained, the abundance of drill core permits the classification of rock units using both primary textures and composition, as indicated by metamorphic mineral assemblages. An attempt has been made to keep map unit notations consistent with existing maps.

STRATIGRAPHY

The Marg property is primarily underlain by a thrust panel between the Robert Service and Tombstone thrust faults (Abbott, 1990a,b). This thrust panel consists of four major stratigraphic/lithologic groups within the property map area (Fig. 3). A precise stratigraphic progression within this thrust panel is difficult to determine due to extensive folding and faulting. However, chronological data, discussed below, provides a reasonable context with which to order the various map units. These map units consist of the following: the Late Precambrian to Early Cambrian Hyland Group (PCh); probable Earn Group rocks, which includes a package of black shales and graphitic argillite (DMps); felsic fragmental metavolcanic rocks (DMv); a mixed metasedimentary, metavolcanic and carbonate package (DMvs); Mississippian Keno Hill Quartzite (Mq); and Triassic diorite to gabbro dykes and sills (Td).

HYLAND GROUP

Unit PCh

The oldest rocks within and surrounding the Marg property are believed to be Neoproterozoic to Lower Cambrian Hyland Group siliciclastic metasedimentary rocks (PCh on Figs. 2, 3). Rock types included in this unit regionally are quartz sandstone, quartzite, quartz-feldspar grit, buff-weathering grey phyllite, buff- to grey-weathering limestone, and silty to sandy limestone that locally grades to calcareous grit (Gordey, 1990). Within the Marg area, lithologies consist of dirty sandstones or greywackes, quartzo-felspathic grits, phyllite and minor carbonate and mafic volcanic rocks. The minor units, a thin, relatively pure marble (PCmb) and a thin sequence of mafic volcanic rocks (PCmv) have been broken out (Fig. 3) as these units are distinctive and may be useful as marker horizons.

The Hyland Group is the lowest mapped unit in the property area and is distinctive due to an abundance of blue, relatively coarse-grained, quartz grains. These rocks, situated just north of the Marg deposit (1.5 km), were initially mapped as Hyland Group by Abbott (1990a), but were later considered (Abbott, 1990b) to belong to a younger (Mississippian?) suite of volcanic and volcaniclastic metasedimentary rocks. Lithologies present on the Marg claims are typified by the presence of blue quartz grains, not observed in any of the overlying rocks, and closely match the description of the Hyland Group provided by Gordey (1990) for the map area immediately south of the Marg property. On the Marg property, the Hyland Group rocks are separated from the overlying Earn Group stratigraphy by a thrust fault, which, although not exposed, is inferred from a subtle upwards truncation of stratigraphy from east to west. Intrusive rocks are not observed crossing this contact. The lower contact of the Hyland Group is the Tombstone Thrust Fault (Abbott, 1990b). The upper thrust, which places younger on older rocks, may represent later movement on a synclinal infold of the Hyland Group within the Earn Group. Hyland Group rocks above the Robert Service Thrust Fault were not investigated.

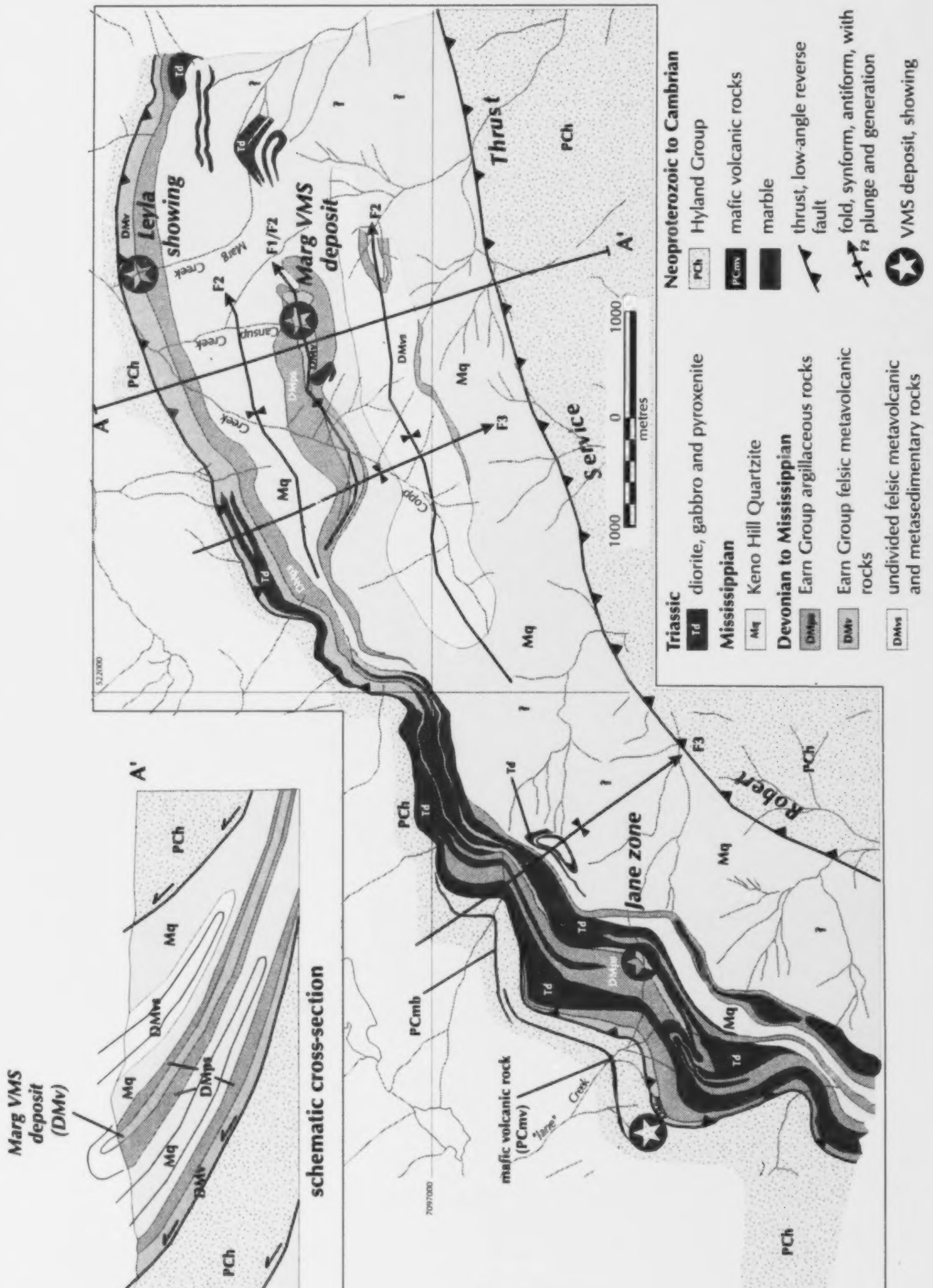

Marg VMS deposit (DMv)
schematic cross-section
A
A'
Mq
DMvs
DMps
DMv
PCh
N
mafic volcanic rock (PCmv)
"Jane" Creek
PCmb
Jane zone
Td
Robert
Service
Thrust
F3
F2
F1/F2
Leyla showing
Marg VMS deposit
Marg Creek
Cansup Creek
Copp Creek
1000
0
1000
metres
7097000
522000
Triassic
Td diorite, gabbro and pyroxenite
Mississippian
Mq Keno Hill Quartzite
Devonian to Mississippian
DMps Earn Group argillaceous rocks
DMv Earn Group felsic metavolcanic rocks
DMvs undivided felsic metavolcanic and metasedimentary rocks
Neoproterozoic to Cambrian
PCh Hyland Group
PCmv mafic volcanic rocks
marble
thrust, low-angle reverse fault
fold, synform, antiform, with plunge and generation
VMS deposit, showing

Figure 3. Property-scale geology map of the Marg property.

During mapping, the Hyland Group rocks were defined by an abundance of blue quartz grains, both within greywackes or grits and within quartz and sericite-rich phyllites that are thought to be distal or reworked tuffaceous rocks. Meta-tuffaceous rocks are fine-grained, strongly foliated, and lack primary macroscopic volcanic features, except rare, lapilli-sized, lithic fragments. They occur as 1- to 15-m-thick bands intercalated with argillaceous and siliceous (greywacke) metasedimentary rocks. The overall sequence of the Hyland Group is generally thick-bedded and may have a total thickness in excess of 1 km. Sulphide mineralization was recently discovered to be associated with altered meta-tuffaceous rocks of the Hyland Group, in the Jane zone vicinity. This mineralization is in close proximity to mafic volcaniclastic and mafic rocks (see below) but lacks the anomalous base and trace element chemistry associated with the mineralization in the Earn Group.

Unit PCmf

Mafic volcanic rocks were discovered in the western part of the property, enclosed within metasedimentary rocks of unit PCh. These mafic volcanic rocks occur as thin bands, from 1 to 10 m thick, along what is interpreted to be a single stratigraphic horizon. Mafic rocks are characterized by a fine-grained matrix of chlorite and amphibole. Volcanic textures include quartz and calcite amygdules, which may indicate basalt flows deposited in a sub-aerial to sub-aqueous environment. In one location, the rocks seemingly display pillow shapes with fine-grained chloritic rinds and siliceous knots within rind (pillow?) interstices. These basalts are the only mafic flow rocks discovered to date on the Marg property. Mafic, probably volcaniclastic rocks, are intimately associated with the interpreted flow rocks, forming thin (<10 m) but laterally continuous bands. Mafic volcaniclastic lithologies have a large biotite component that together with grey, fine-grained, feldspar and quartz bands, defines alternating millimetre-scale microlithons. Mafic clastic rocks can contain minor (up to 10%) blue quartz grains that are coarser-grained than the surrounding matrix. Mafic flow and volcaniclastic rocks have similar chemistry, which indicates that these rocks are alkali basalts with anomalous levels of barium (4000 ppm) and zirconium (300–500 ppm).

Unit PCmb

Weakly foliated, homogeneous marble, hosted within metasedimentary rocks of the Hyland Group, occurs as thin, 5- to 25-m-thick bands that are laterally continuous for distances of 1 km. The white to pale brown marble is a minor component of the overall stratigraphy, and suggests a brief period of deposition within a shelf sequence in a shallow marine environment.

EARN GROUP

Metasedimentary and metavolcanic rocks form three distinct sequences on the Marg property, one of which is a 300-m-thick, but folded, succession that surrounds and hosts the Marg deposit. These rocks are correlated with the Earn Group, although lack of clear diagnostic features such as fossils or the chert-pebble conglomerate unit (Abbott, 1990a) makes this correlation tentative. Zircons from quartz-phyric sericite schist (crystal tuff; Turner and Abbott, 1990a) have poor U-Pb systematics but yield a minimum age of 344 Ma (Mortensen, pers. comm., 2001). Zircons from other units within this sequence have similarly poor U-Pb systematics but yield dates ranging from 368 to 375 Ma indicating a probable early Late Devonian age (J.K. Mortensen, pers. comm., 2001).

The Earn Group rocks have been informally subdivided into three map units, which are structurally, and probably stratigraphically interlayered with the Keno Hill Quartzite. The units are described in structural sequence. The 'upper' package (DMvs) of metasedimentary rocks consists of graphitic, argillaceous material with abundant intercalations of fine-grained volcaniclastic rocks and, locally, thin carbonate lenses. The 'middle' unit (DMps) is composed of black argillaceous rocks (graphitic schist). The 'lower' unit (DMv) is a volcanic sequence composed of quartz- and feldspar-phyric tuffs and possible flows, fine-grained ash tuffs and related volcanic sedimentary rocks, and massive sulphide mineralization.

Unit DMvs

This unit occurs as a synclinal keel located approximately 1 km south of the Marg deposit and consists of intercalated argillaceous metasedimentary rocks with subordinate, thin, pale green, fine-grained tuffs and limestone lenses. Outcrop exposures consist of brown to dark grey phyllites, minor pale green phyllites and white to cream coloured limestone. The significant differences between this unit and the other units correlated with the Earn Group is the lower graphite and quartz contents of the sediments, fine grain-size of the tuffaceous rocks, and most importantly, the presence of limestone lenses. Contacts with Keno Hill Quartzite are only exposed in a few locations and are sheared in all but one, where the contact appears to be gradational.

Unit DMps

This unit is primarily composed of graphitic, argillaceous metasedimentary rocks with minor metatuffaceous rocks. The sedimentary rocks are characterized by a phyllitic metamorphic and structural character, with fine alternating quartz and graphitic microlithons. This unit is defined as being approximately 90% black shale or mudstone with only minor intervals of volcanic ash and no quartzite. Minor intercalations of quartzite invariably signal the start of the Keno Hill Quartzite unit. There is significant variation in the silica content of the black shales as indicated by the presence of up to 40% quartz 'sweats' within the argillite, notably, those proximal to mineralization. Graphitic argillites of the Earn Group indicate a deep-water, off-shelf depositional setting (Roots, 1997a).

Unit DMv

Felsic, metavolcanic rocks are the primary host to the Marg massive sulphide deposit. Lithologies range from lithic and crystal-lithic ash tuffs through rare lapilli tuffs to coarse-grained, quartz-feldspar crystal tuffs or flows. Typically, these lithologies are yellow green to medium dark green depending upon relative amounts of muscovite and chlorite. Lithic fragments, grain-size and even phenocrysts are difficult to discern in outcrop, except on weathered, lichen-free surfaces, but are readily visible in drill core. Volcanic lithologies are generally thin (<25 m) and commonly interbedded with minor argillaceous material. Contacts between volcaniclastic units are commonly gradational, whereas contacts between volcaniclastic and sedimentary lithologies can be either sharp or gradational.

Coarse-grained quartz porphyry occurs between massive sulphide layers, near the central part of the deposit, and both unit thickness and quartz (± feldspar) grain size diminish along strike in both directions, as well as down dip, suggesting a possible flow-dome complex or the centre of a pyroclastic flow channel.

Earn Group felsic metavolcanic rocks are thought to be mainly pyroclastic flows based on observed textures in drill core as well as their lateral extent (kilometres) relative to thickness, limited compositional variation, and lack of broken phenocrysts. These features suggest volcanic derivation from a regional felsic dome or intrusive complex (Roots, 1997a).

KENO HILL QUARTZITE

Unit Mq

The Keno Hill Quartzite (Green, 1971) consists of black to dark-grey weathering (but light grey on fracture surfaces), homogeneous, fine- to medium-grained, 'clean', quartz-rich (>90% quartz) rock, commonly containing 2- to 30-m-thick intercalations of graphitic argillite and rare interbeds of metatuffaceous rocks. The quartzite is anomalously thick and laterally extensive within the Marg area (Abbott, 1990a) commonly forming extensive lenses in excess of 100 m thick. The Keno Hill Quartzite is intruded by deformed, Triassic (?) meta-diorite to meta-pyroxenite sills and/or dykes. A Mississippian age of the Keno Hill Quartzite is indicated from fossil evidence at a number of localities in the Dawson area (Mortensen and Thompson, 1990; and Orchard, 1991).

Quartzite and intercalated argillite likely had sandstone and shale protoliths that were deposited in a near-shore environment. This is based on the occurrence of non-marine plant fossils and gastropods (Roots, 1997a; Tempelman-Kluit, 1970). Contacts between the quartzite and probable Earn Group rocks are commonly fractured due to the rheological differences, however, unfractured, both gradational and sharp contacts with argillite and tuffaceous rocks are observed within drill core, suggesting conformable relations with adjacent rocks on the Marg property.

INTRUSIVE ROCKS

Unit Td

Metasedimentary and metavolcanic rocks of the Keno Hill Quartzite and Earn Group in the Marg map area are intruded by deformed meta-diorite to meta-pyroxenite dykes and/or sills and undeformed Cretaceous (?) granite to granodiorite plutonic rocks (Abbott, 1990a). The Cretaceous intrusions have pervaded the stratigraphy within the Mt. Westman map area (106D/1) and Abbott (1990a) interprets this to indicate that much of the region may be underlain by Cretaceous granitic stocks.

The mafic intrusive rocks are part of a belt, which extends for at least 200 km to the northwest (Green, 1972; Abbott, 1990a). These rocks have an indicated Triassic age, based on a zircon and baddelyite U/Pb age of 232 ± 1.5-1.2 Ma, obtained on a sample from the

Tombstone Range, (Mortensen and Thompson, 1990) in the northwestern end of the belt. Within the Marg area, the mafic intrusive rocks are typified by medium-grained, equigranular, euhedral hornblende-plagioclase diorite to gabbro that locally contains porphyritic K-feldspar. In isolated locations, the gabbros have differentiated K-feldspar- to plagioclase-rich margins that may indicate tops. Larger bodies of these intrusive rocks have been observed to contain pyroxenite cores. Intrusive bodies vary in thickness between 10 and 150 m and have strike extents up to 3.5 km. Hornblende and pyroxene within these dykes or sills is frequently replaced or pseudomorphed by actinolite, chlorite or fuchsite.

Contacts of the intrusive rocks with surrounding older metasedimentary and metavolcanic rocks are typified by moderate to intense ferroan carbonate alteration and/or hornfelsed metasedimentary rocks. These contact zones are generally 5–15 m thick and commonly extend for considerable lengths along the intrusive body. The sills locally contain sheet-like xenoliths of foliated Earn Group argillite, Earn Group tuff or Keno Hill Quartzite (up to 10 m in length). Chilled margins within diorite are defined by a conspicuous reduction in grain size, although the margins and contact aureoles are less developed where intrusions are thin (10–20 m).

The medium-grained crystalline nature of the majority of the intrusive rocks suggests emplacement into the surrounding metasedimentary and metavolcanic rocks at depth, where residency times were long enough to accommodate significant crystallization.

There is the possibility of an older suite of mafic intrusions, which occur in the vicinity of the sulphide deposit. Thin, mafic intrusions proximal to the sulphide deposit display unusual textures, some that resemble peperites, possibly indicating intrusion into wet sediments. Termed 'greenstone' in drill logs, these units are commonly fine-grained, foliated and occur in various stages of iron-carbonate replacement, which varies from pale yellow to bright orange. The thicker units (>5 m) generally have green core zones with pervasive iron carbonate alteration along the margins. Iron carbonate alteration may also be replacing part of the host rocks adjacent to the intrusive contact, and may partly account for some of the unusual textures. As all of the intrusions were emplaced prior to deformation, it is not possible to distinguish syngenetic from epigenetic intrusions based on deformation state. Chemical analyses from the mafic intrusions are pending and may help determine if there is any difference between the mafic intrusive units.

STRUCTURAL GEOLOGY

Rocks within the Marg deposit area record a complex history of strain and deformation during the Jurassic to Cretaceous orogeny. Deformation has substantially modified the geometry of massive sulphide mineralization and its host rocks. Three distinct structural events are preserved and likely represent a continual deformation sequence that accommodated crustal shortening in both northwesterly and northeasterly directions. Structural data is presented in Fig. 4a, whereas actual structures are shown in Fig. 4b. A schematic illustration of structural features, fold geometries and the effect on mineralization is presented in Fig. 4c, which is similar to that presented by Gordey (1990) for the Tiny Island Lake map area.

Generation 1 structures

The earliest generation of deformation (D_1) observed within the area is marked by northeast-vergent, isoclinal folds (F_{1a}) that deform primary features. Fold closures were rarely observed, but where visible, plunge moderately (35° to 45°) to the southeast (100° to 130°). These folds contain axial surfaces that dip 35° to 45° to the south-southeast (120° to 160°), parallel to the regional south-southeast dip of bedrock within the region. In areas of higher strain, defined by intense foliation (S_1) that completely transposes all earlier features, phase 1 is represented by sheath folds (F_{1b}). Sheath folds are contained within the plane of maximum strain (S_1), exhibit parallel fold hinges with opposing asymmetry, plunge to the southeast, and are recognizable as minor folds in outcrop by characteristic elliptical features referred to as 'lipstick pattern' (Fig. 4b). Larger scale sheath folds are manifested as the double fold closures or elliptical outcrop patterns of unit DMv in the Marg deposit area (Fig. 3). The presence of sheath folds (F_{1b}) is supportive of a ductile shear zone style of deformation and may be related to northwest-vergent deformation (Murphy, 1997) associated with the Tombstone strain zone.

Generation 2 structures

The second generation of deformation (D_2) is characterized by tight to isoclinal asymmetric folds (F_2) that deform phase 1 isoclinal and sheath folds. Phase 2 folds are recognizable as map-scale structures (200–500 m) that fold contacts between the Earn Group, Keno Hill Quartzite and mafic intrusions. These fold structures verge to the northeast and have fold hinges that are coaxial with older F_1 folds. Foliation (S_2) related to this phase results in a crenulation cleavage and S_1/S_2 intersection lineation (L_2).

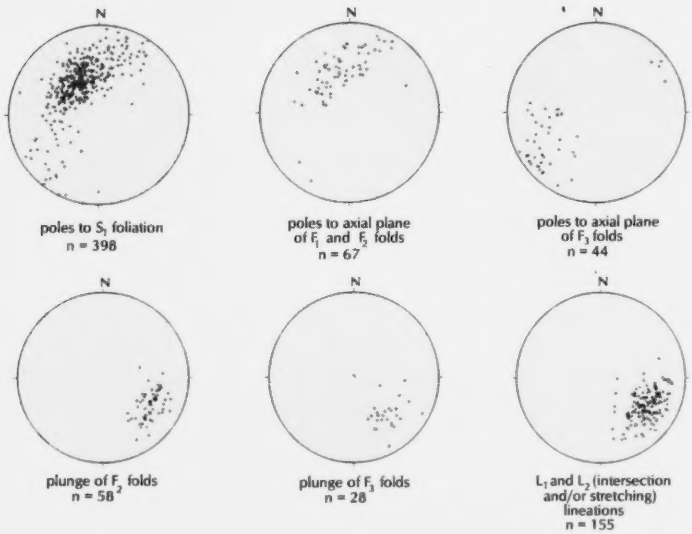
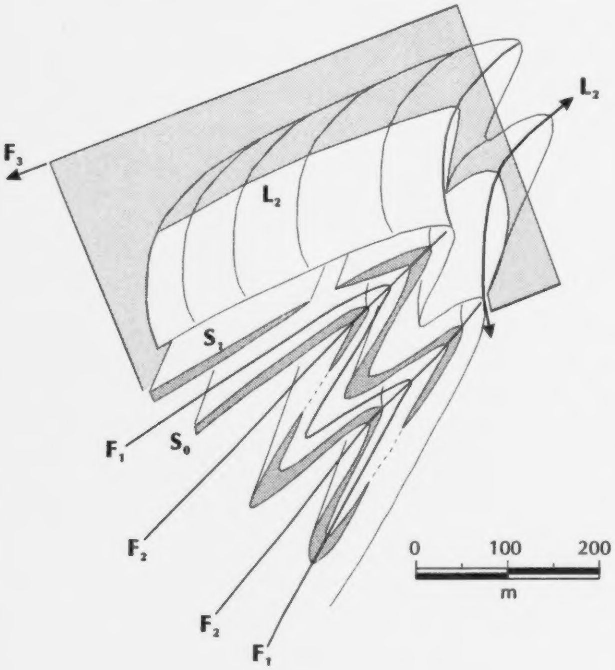


Figure 4a. *Stereographic presentation of structural data.*

Figure 4c. *Schematic illustration of fold styles on the Marg property. Folded bedding (S_0), or massive sulphide mineralization, may be attenuated along limbs. Penetrative cleavage (foliation, S_1) is folded by F_2 folds which are coaxial to F_1. Intersection of F_2 axial planar cleavage (S_2) with S_1 produces L_2 lineations. F_1 hinge lines may be irregular due to formation of sheath folds (F_{1b}, not shown). F_2 and F_1 axial traces plunge moderately to the southeast. F_3 folds are generally open with upright axial planes and gentle to moderate plunges to the southeast. Actual folds are tighter than shown.*



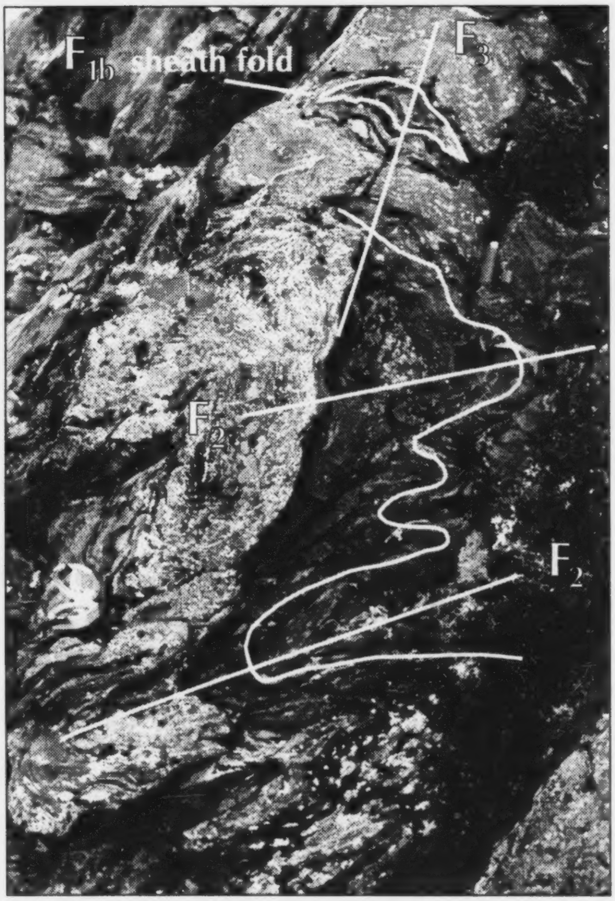


Figure 4b. *Photograph illustrating the relation between F_{1b} sheath fold (note opposing closure, identical plunge), F_2 northeast-vergent, isoclinal S-folds, and late open F_3 non-coaxial folds. Lithology is unit DMvs (metasedimentary rock). Note compass in lower left of photo for scale; compass needle is oriented north.*

Generation 3 structures

Phase 3 deformation (D_3) is non-coaxial with earlier folds, and is represented by open to tight folds (F_3) that deform map- and outcrop-scale D_1 and D_2 folds and foliations (Fig. 4b, c). F_3 folds verge to the southwest and have steep to upright (45° to 85°) axial surfaces that strike west-northwest (290° to 330°).

Significance to exploration

The Marg polymetallic massive sulphide deposit has been deformed by all three phases of deformation described above. The deposit is interpreted to be hosted within an early F_1 fold (or F_{1b} sheath fold) that has been subsequently deformed during coaxial D_2 deformation and non-coaxial D_3 deformation (Fig. 4c). In cross-section, the F_2 fold is an M-shaped fold, and the deposit shifts from being concentrated in the southern limb to the northern limb going from west to east.

Exploration drilling at the eastern end of the deposit (section 21+00 E, Fig. 5) intersected massive sulphide mineralization that terminates along strike to the east within isoclinal fold hinges. Mineralization plunges 45° to the southeast within coaxial F_1/F_2 fold closures. At the western end of the deposit, mineralization was observed to terminate along section 10+00 E, which could be due to the closure of stratigraphy within an isoclinal (sheath) fold hinge (mapped on surface). The termination of the stratigraphy on both ends of the deposit in folds that are geometrically correlative and have the same plunge and opposite sense of closure, supports the hyposthesis that the Marg deposit is contained within the core of an F_{1b} sheath fold. Mineralization is known to continue down plunge along the eastern fold nose and is interpreted to continue at depth along the southeast plunge of the western closure. In a similar fashion, the Marg host stratigraphy is repeated west of the deposit area in another elliptical shaped sheath fold (Fig. 3); an area that hereto has received minimal exploration.

Non-coaxial F_3 folds deform the stratigraphy of the Marg sequence, but are not visible on the north-south drill sections as the fold axial trace strikes at a low angle (300°) to the north-south sections. F_3 folds are more obvious in longitudinal sections and plan, where they

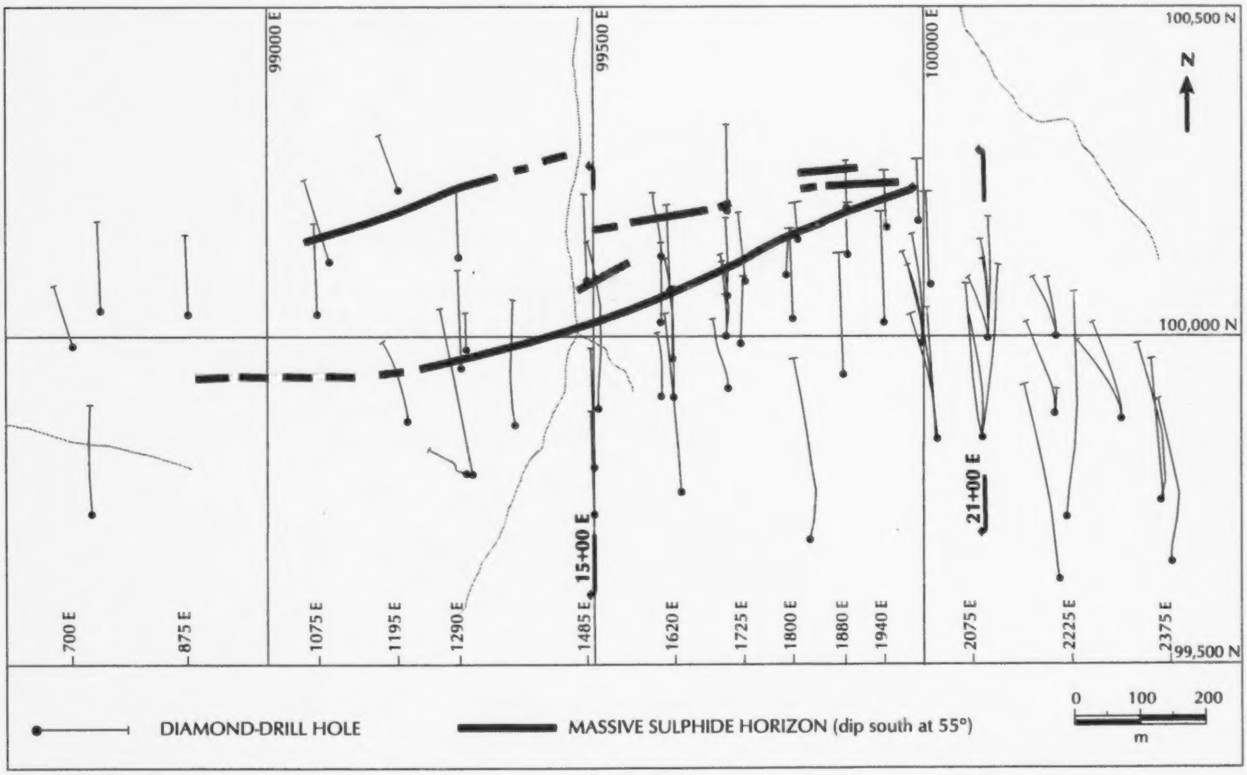


Figure 5. *Diamond-drill hole plan of the Marg property, displaying section locations.*

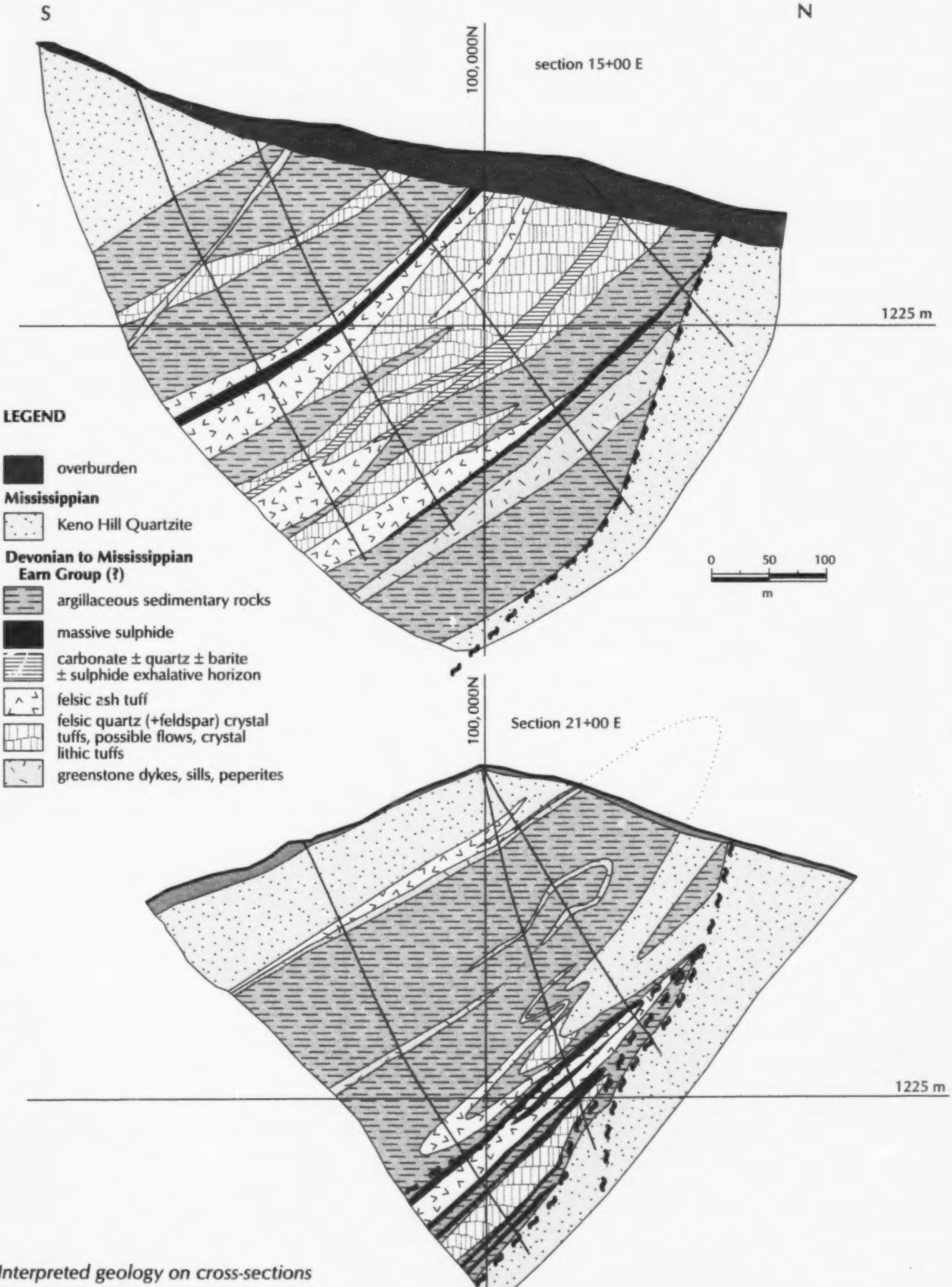

S
N
100,000N
section 15+00 E
1225 m
LEGEND
overburden
Mississippian
Keno Hill Quartzite
Devonian to Mississippian
Earn Group (?)
argillaceous sedimentary rocks
massive sulphide
carbonate ± quartz ± barite ± sulphide exhalative horizon
felsic ash tuff
felsic quartz (+feldspar) crystal tuffs, possible flows, crystal lithic tuffs
greenstone dykes, sills, peperites
0
50
100
m
100,000N
Section 21+00 E
1225 m

Figure 6. *Interpreted geology on cross-sections 15+00 E and 21+00 E of the Marg property.*

broadly fold the mineralized horizons. These folds will vary the drill depth to massive sulphide intersections along the length of the deposit.

Although not directly connected with Marg deposit host rocks, both the Jane zone and the newly discovered showing Leyla zone occur in structural continuations of the prospective DMv stratigraphy.

MINERALIZATION AND ALTERATION

The Marg deposit is made up of a series of continuous to discontinuous sheets of massive and semi-massive sulphide mineralization. Up to eight sulphide sheets can occur on a single section although most of the mineralization occurs within four sheets. A resource estimate was calculated by Franzen (1997), using the polygonal method and a minimum 3 m true thickness of 135 drill intercepts in 76 holes; this estimate is 5,527,000 tonnes grading 1.76% Cu, 2.46% Pb, 4.60% Zn, 62.7 g/t Ag and 0.98 g/t Au. The resource is contained in parallel sheets within an area 700 m along strike and 450 m down-dip. The average thickness of the >3 m intersections is 6.0 m (Fig. 6). The upper two sulphide horizons account for 82% of the resource.

Sulphide mineralization occurs at, or near, the contact between footwall volcaniclastic rocks and hanging wall argillaceous sediments. It is believed that the mineralized stratigraphy occurs within a refolded sheath fold that appears as an approximate 'M' shape in cross-section (Fig. 6). Minor folds, irregular stratigraphy, attenuation along isoclinal fold limbs, and foliation parallel faults with minor displacement, further complicate the geometry. It is probable that the main sulphide sheets represent a single refolded sulphide lens, an interpretation that is not particularly critical to exploration, but is supported by Turner and Abbott (1990), who documented the zonation of sulphide assemblage facies and metal ratios. Metal ratios, although variable within a single sheet, do not display any statistical differences between the various mineralized sheets, which might be expected if the sheets were separate stratiform deposits.

Mineralization is concentrated within the southern and central limbs of the 'M' fold in the western part of the deposit, but becomes progressively concentrated in the northern, or lower fold nose to the east (and down plunge), as illustrated in the two cross-sections of Figure 6. This transition from upper to lower fold limbs indicates that the original strike of the deposit was at a shallow angle to the F_2 fold structure. The cross-sections are not completely orthogonal to the strike direction and therefore dips appear to be shallower than they are in reality.

The lower contacts of the sulphide host rocks are locally truncated by the quartzite unit and the contacts are marked by fracturing or narrow intervals of gouge, which has been previously interpreted as a thrust fault. Kinematic indicators are lacking and sense of movement and actual displacement are not known, however, these faults are brittle fractures, which cut all deformation fabrics, including F_3 folds, and are therefore, unrelated to the regional thrust faulting (D_1/D_2).

Sulphide minerals consist of pyrite, sphalerite, chalcopyrite, galena, tetrahedrite and arsenopyrite in a gangue of quartz, ferroan carbonate, muscovite and rare barite. Magnetite is notably absent. It is probable that sulphide textures have been modified by strain but compositional layering on the millimetre to centimetre scale may be primary. Sulphide sheets are massive to semi-massive, with sharp, or less commonly, gradational, interlayered contacts. Alteration haloes of pervasive muscovite and carbonate are moderately developed and most conspicuous within the volcanic rocks. Black chlorite occurs locally, most notably near the up-dip footwall of the upper sheet. Because of the close proximity of the sulphide sheets, it is difficult to discern where the footwall alteration of one sheet ends relative to the hanging wall alteration of the adjacent sheet, or vice versa. Alteration is accompanied by enrichment in base metals as well as Hg, Mo, As, Ag, Ni, Ba and Mn. Lithogeochemical studies are ongoing and although zonation of 'indicator' elements does not appear to be as consistent and reliable as in some deposits, lithogeochemistry will still be useful to exploration, particularly within the argillaceous rocks where mineral alteration is not visually distinctive.

Sulphide mineralization is commonly overlain or underlain by silica, ferroan carbonate and more rarely, barite layers of possible exhalative (± replacement) origin. Exhalative horizons range from 3 to 300 cm thick and are most prominent in the central to eastern part of the deposit, commonly marking the structurally inferred location of the sulphide horizon where sulphide mineralization is minimal or absent. Interpreted exhalites are highly anomalous in base and precious metals as well as the indicator elements.

Lithogeochemical haloes (elements listed above) surrounding the massive sulphide horizons generally display both a decrease in thickness and intensity in the down-dip direction for all sulphide horizons, but most notably in the two upper (southernmost) horizons. This down-dip decrease is also more pronounced in an overall westerly direction. These trends in lithogeochemistry reflect the overall antiformal structure of the 'M' fold and the southeasterly plunge direction. A corresponding decrease in the thickness and grain size of the quartz-feldspar-phyric pyroclastic/flow rock and zonation of chloritic alteration suggests that the original, central core zone of the deposit was situated up-dip from surface and has been eroded. Thus, the original deposit may have been substantially larger prior to erosion.

DISCUSSION

Although deformation at the Marg property is probably too extreme to fully reconstruct the stratigraphy and setting of the Marg deposit, detailed studies of the lithologies, alteration, structure and lithogeochemistry are shedding light on the nature of the deposit and, more importantly, on the exploration potential of the property.

Exploration potential within the Marg property is high. Recognition of the structural style of the sheath folds allows the prediction of the location of prospective stratigraphy in the sub-surface. Mapping and prospecting have discovered structural repetitions of the volcanogenic massive sulphide (VMS) host stratigraphy that contain sulphide occurrences, such as the Leyla showing zone, which highlight the potential for discovery of new zones of massive sulphide mineralization. The previously discovered Jane zone is hosted by the strike extension of the Marg deposit host rocks, however, the thickness of the volcanic package and the intensity of alteration appears to be significantly greater than that present in the Marg area.

An 'undeformed' Marg deposit displays many features that are similar to the VMS deposits of Yukon-Tanana Terrane, namely the Kudz Ze Kayah (KZK) and Wolverine (Hunt, 1997; Tucker et al., 1997) deposits, and deposits of the Bonnifield district, Alaska. Marg metal ratios are most similar to KZK, whereas the alteration and setting (most notably, the tabular massive sulphide mineralization overlying a thin sequence of felsic crystal tuffs, flows and related volcaniclastic rocks within a thick package of sedimentary rocks) is more similar to the Wolverine deposit. Further studies will compare the chemistry of the volcanic rocks hosting the Marg deposit with those at Wolverine and elsewhere. Do the Marg volcanic rocks represent a slice of Yukon-Tanana-equivalent rocks imbricated into, and deformed along, the Tombstone strain zone? Stratigraphic evidence indicates probable conformity between the volcanic rocks and the Keno Hill Quartzite supporting VMS formation within the Selwyn Basin.

Geochemical, geological and structural data suggest that the central core zone of the deposit has been eroded, supporting speculation that the original deposit may have been two or three times larger than what is indicated by the estimated resource. The amount of volcanic rock, in relation to the massive sulphide mineralization, is relatively minimal, (a possible sub-volcanic intrusion, or reasonable facsimile, is inferred to have been present lower in the stratigraphy, prior to thrust faulting) making regional exploration based on mapping difficult. Given the overall size of the Selwyn Basin and the limited stratigraphic thickness of volcanic rocks required to host Marg-style VMS deposits, the potential for undiscovered VMS deposits is significant (Roots, 1997b).

Massive sulphide mineralization is spatially, and probably genetically, related to quartz-phyric volcanic rocks that likely originated within rift basins related to faults along the shelf edge of the continental miogeocline. The Keno Hill Quartzite, although the most resistant, and therefore, most prominent rock within the host stratigraphy, is likely not significant to mineralization. Anomalous thickness of the quartzite unit may, however, indicate the presence of a rift-related basin.

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Geological characteristics of high-level subvolcanic porphyritic intrusions associated with the Wolverine Zn-Pb-Cu volcanic-hosted massive sulphide deposit, Finlayson Lake District, Yukon, Canada[1]

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ABSTRACT

During the 2000 field season, a project was initiated to study the geology, geochemistry and alteration characteristics of high-level subvolcanic porphyritic intrusions associated with the Wolverine volcanic-hosted massive sulphide deposit in the Finlayson Lake district, Yukon. Subvolcanic porphyritic intrusions within the Wolverine deposit are located approximately 10-20 m beneath exhalative sulphide bodies or iron-formation in four zones (Wolverine/Lynx, Fisher, Sable and Puck). Most intrusions are K-feldspar porphyritic (Fisher and Wolverine/Lynx Zones); however, a few are quartz and K-feldspar porphyritic (Puck and Sable zones). Feldspar-porphyritic intrusions consist of euhedral to subhedral grains of K-feldspar in a grey fine-grained matrix. Quartz-feldspar porphyritic intrusions contain slightly smaller feldspar crystals and blue to black glassy quartz eyes set in a fine-grained matrix. Most of the intrusions have non-peperitic upper margins with carbonaceous argillite (Wolverine/Lynx, Fisher, Puck). Some of the quartz-feldspar porphyritic intrusions are in contact with fine-grained volcaniclastic rocks along their upper margins (Sable); both types of intrusions have lower contacts with fine-grained volcaniclastic sedimentary rocks. These intrusions are, for the most part, unaltered and have only minor sericite-silica±chlorite±pyrite alteration and small mm- to cm-scale veinlets of quartz-sericite±chlorite±pyrite± sphalerite. This suggests a pre- to syn-mineralization timing for the emplacement of the intrusions. The contribution of these intrusions to the heat and metal budget of the Wolverine deposit is the focus of ongoing research.

RÉSUMÉ

Un projet a été entrepris au cours de la saison des travaux de terrain de l'an 2000 afin d'étudier les caractéristiques géologiques, géochimiques et d'altération des intrusions subvolcaniques porphyriques présentes dans la partie supérieure du gisement de sulfure massif encaissé dans des roches volcaniques de Wolverine. Dans ce gisement, les intrusions porphyriques subvolcaniques se trouvent dans quatre zones (Wolverine/Lynx, Fisher, Sable et Puck), à environ 10 à 20 m en moyenne sous les sulfures exhalatifs ou les formations de fer. La plupart de ces intrusions sont composées de porphyres à feldspath potassique (zones de Fisher et de Wolverine/Lynx), bien que quelques-unes soient formées de porphyres à quartz et feldspath potassique (zones de Puck et de Sable). Les intrusions de feldspath porphyrique renferment des grains de feldspath potassique automorphes à hypidiomorphes enrobés dans une matrice grise à grain fin. Les intrusions quartzo-feldspathiques porphyriques contiennent des cristaux de feldspath légèrement plus petits et du quartz oeillé vitreux de couleur bleu à noir englobé par une matrice à grain fin. La plupart des intrusions sont entourées dans leur partie supérieure de bordures dépourvues de péperite et renfermant des argilites carbonacées (zones de Wolverine/Lynx, Fisher et Puck). Cependant, certaines intrusions quartzo-feldspathiques porphyriques se trouvent en contact avec des roches sédimentaires volcanoclastiques à grain fin le long de leurs bordures supérieures (zone de Sable). Les deux types d'intrusions sont en contact, dans leur partie inférieure, avec des roches sédimentaires volcanoclastiques à grain fins. Bon nombre de ces intrusions ne sont pas altérées et n'ont été l'objet que d'une légère altération en séricite-silice±chlorite±pyrite; elles ne contiennent que de petites veinules millimétriques à centimétriques de quartz-séricite±chlorite± pyrite±sphalérite. Ces caractéristiques permettent de supposer que les intrusions ont été formées avant ou pendant la minéralisation. Le rôle relatif que celles-ci ont joué dans le bilan calorifique et métallique du gisement de Wolverine est l'objet principal des recherches en cours.

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INTRODUCTION

Numerous workers have suggested that subvolcanic intrusions play a critical role in the generation and maintenance of hydrothermal systems responsible for the formation of volcanic-hosted massive sulphide (VHMS) deposits (Campbell et al., 1981; Cathles, 1981, 1983; Lesher et al., 1986; Galley, 1996; Large et al., 1996; Barrie et al., 1999). Most workers suggest that these high-level subvolcanic intrusions provide the heat for generating and maintaining hydrothermal systems (Campbell et al., 1981; Galley, 1996; Barrie et al., 1999), and some workers also suggest that these intrusions may contribute metals to the hydrothermal system (Large et al., 1996).

As part of the Ancient Pacific Margin NATMAP project (Thompson et al., 2000) and the Finlayson Lake Project, funded under the proposal approval system of GSC (Project PAS1017), the authors have undertaken a study of subvolcanic intrusive rocks in the Finlayson Lake district (FLD), southeast Yukon. Within the Wolverine VHMS deposit, high-level subvolcanic porphyritic intrusions are spatially associated with massive sulphide mineralization in many areas. Herein we provide field and petrographic observations of these high-level subvolcanic porphyritic intrusions. This paper is a companion to a more extensive study of the genesis and setting of the Wolverine VHMS deposit (Bradshaw et al., this volume) and on chemical sedimentary (exhalative) rocks associated with this deposit (Peter et al., in prep.).

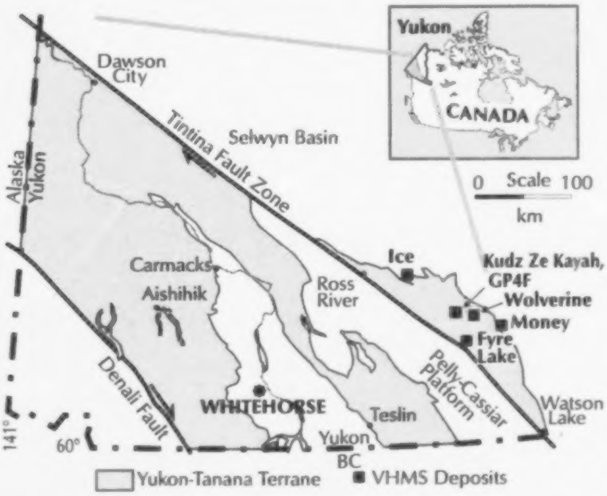

Figure 1. *Geological setting and distribution of the Yukon-Tanana Terrane in the Yukon, and the location of the study area with respect to the Finlayson Lake region. Map modified from Hunt (1998).*

REGIONAL SETTING

The Finlayson Lake VHMS district (Figs. 1 and 2) is hosted by variably deformed and metamorphosed (greenschist to lower amphibolite facies) Devonian-Mississippian volcanic, intrusive and sedimentary rocks of the Yukon-Tanana Terrane (Tempelman-Kluit, 1979; Mortensen and Jilson, 1985; Mortensen, 1992; Murphy and Timmerman, 1997; Murphy, 1998; Murphy and Piercey, 1999a,b,c, 2000; Piercey and Murphy, 2000; Murphy, this volume). Although the rocks are metamorphosed, most rocks have discernable primary features and, where applicable, the prefix 'meta-' is used in the following text for ease of reading. Murphy and co-workers (*op. cit.*) have broken the volcanic, intrusive, and sedimentary rocks of the district into three stratigraphic successions (Grass Lakes, Wolverine Lake, and Campbell Range successions), which have been formed on a substrate of non-carbonaceous, biotite-rich clastic metasedimentary rocks and associated metacarbonates and marble (unit 1; Fig. 2).

The base of the Grass Lakes succession, unit 1 (metaclastic rocks), is overlain by rocks of the Fyre Lake unit (unit 2), which consist of a Devonian-Mississippian (~365-360 Ma; Mortensen, 1992; Mortensen and Murphy, unpublished data) package of mafic volcanic and intrusive rocks, with lesser felsic volcanic and sedimentary rocks (Fig. 2). These rocks are interpreted to represent arc magmatic activity that progressed to back-arc basin formation (Grant, 1997; Sebert and Hunt, 1999; Piercey et al., 1999, 2000a). Boninitic volcanic rocks within this package host the Besshi-style Cu-Co-Au VHMS deposits (Foreman, 1998; Sebert and Hunt, 1999).

The Kudz Ze Kayah unit (unit 3) stratigraphically overlies the Fyre Lake unit and is a ~360 Ma felsic-volcanic and sedimentary rock dominated unit with lesser mafic volcanic and intrusive rocks and felsic intrusive rocks (Grass Lakes suite intrusions; Fig. 2). These rocks host the felsic-volcanic-associated Zn-Pb-Cu Kudz Ze Kayah and Zn-Pb GP4F VHMS deposits and are interpreted to represent an Okinawa Trough-style ensialic back-arc basin (Piercey et al., 2000a).

The Wolverine succession unconformably overlies the Grass Lakes succession and consists of a lower package (unit 5l) of quartz-feldspar pebble conglomerate, overlain by ~345 Ma (Piercey, unpublished data) rhyolitic flows, volcaniclastic rocks, quartz-feldspar bearing volcaniclastic and epiclastic sedimentary rocks, and high-level feldspar± quartz porphyritic rhyolitic intrusive rocks (unit 5f/qfp; Fig. 2). This felsic-dominated package is overlain by unit

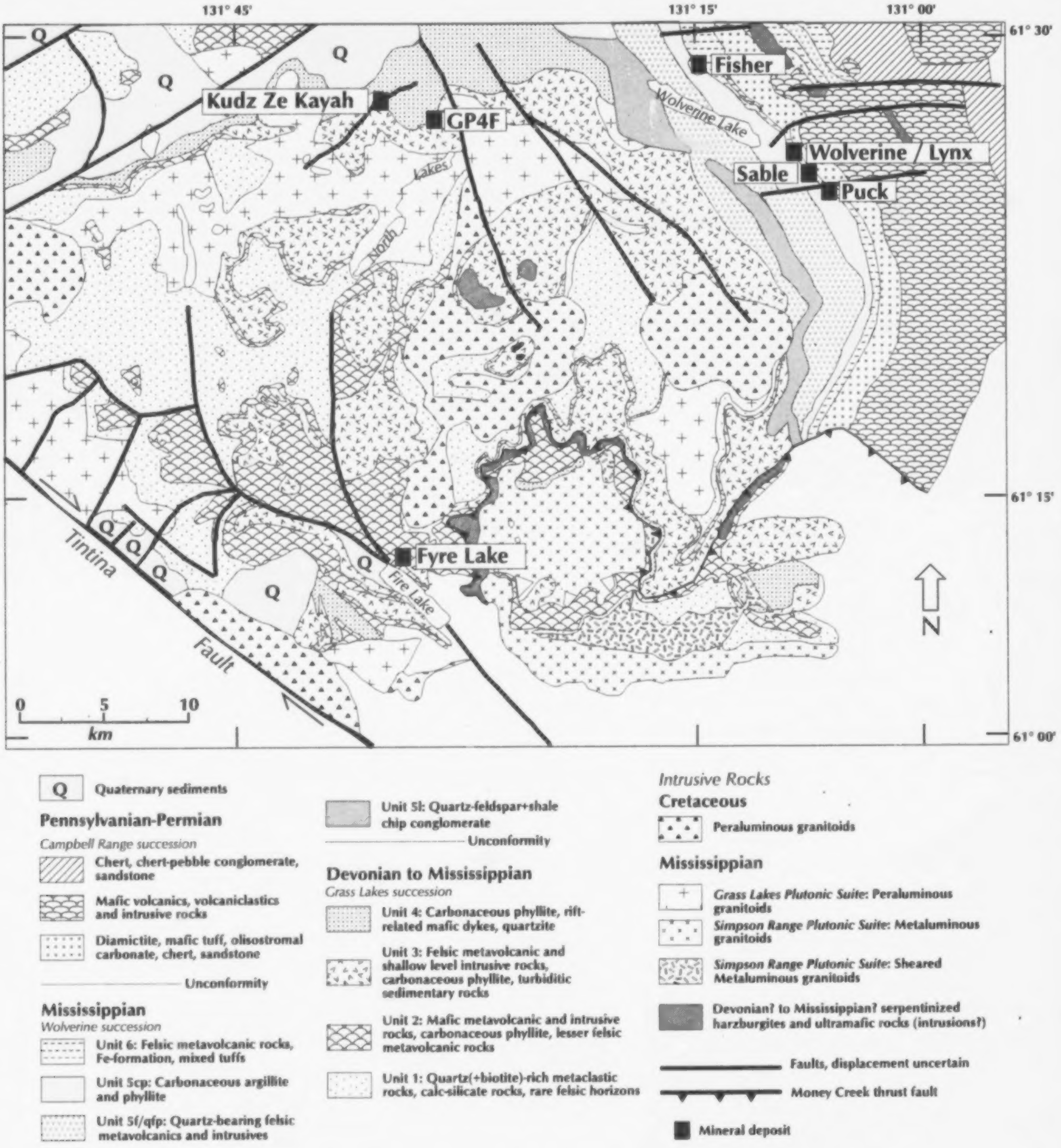
131° 45'
131° 15'
131° 00'
61° 30'
61° 15'
61° 00'
Q
Kudz Ze Kayah
GP4F
Fisher
Wolverine Lake
Wolverine / Lynx
Sable
Puck
North Lakes
Fyre Lake
Fire Lake
Tintina
Fault
N
0
5
10
km
Quaternary sediments
Pennsylvanian-Permian
Campbell Range succession
Chert, chert-pebble conglomerate, sandstone
Mafic volcanics, volcaniclastics and intrusive rocks
Diamictite, mafic tuff, olisostromal carbonate, chert, sandstone
Unconformity
Mississippian
Wolverine succession
Unit 6: Felsic metavolcanic rocks, Fe-formation, mixed tuffs
Unit 5cp: Carbonaceous argillite and phyllite
Unit 5f/qfp: Quartz-bearing felsic metavolcanics and intrusives
Unit 5l: Quartz-feldspar+shale chip conglomerate
Unconformity
Devonian to Mississippian
Grass Lakes succession
Unit 4: Carbonaceous phyllite, rift-related mafic dykes, quartzite
Unit 3: Felsic metavolcanic and shallow level intrusive rocks, carbonaceous phyllite, turbiditic sedimentary rocks
Unit 2: Mafic metavolcanic and intrusive rocks, carbonaceous phyllite, lesser felsic metavolcanic rocks
Unit 1: Quartz(+biotite)-rich metaclastic rocks, calc-silicate rocks, rare felsic horizons
Intrusive Rocks
Cretaceous
Peraluminous granitoids
Mississippian
Grass Lakes Plutonic Suite: Peraluminous granitoids
Simpson Range Plutonic Suite: Metaluminous granitoids
Simpson Range Plutonic Suite: Sheared Metaluminous granitoids
Devonian? to Mississippian? serpentinized harzburgites and ultramafic rocks (intrusions?)
Faults, displacement uncertain
Money Creek thrust fault
Mineral deposit

Figure 2. *Geological map of the Finlayson Lake region modified from Murphy (1998) and Piercey et al. (1999) with locations of different zones of the Wolverine VHMS deposit and other VHMS deposits of the Finlayson Lake district.*

5cp, carbonaceous argillite and quartzite of regional extent, which forms part of the deeper footwall of the Wolverine deposit (Tucker et al., 1997; Bradshaw et al., this volume; Fig. 2). The Wolverine deposit is hosted by unit 6, which consists of rhyolitic volcaniclastic and epiclastic rocks, high-level rhyolitic intrusive rocks and flows, variably carbonaceous sedimentary rocks, and is capped by interlayered felsic and mafic volcaniclastic and basaltic lava flows (cf. Bradshaw et al., this volume; Figs. 2-4). Geochemical compositions of the felsic volcanic rocks in the Wolverine succession suggest that the rocks formed within an ensialic back-arc basin setting, akin to that of the Grass Lakes succession (Piercey et al., 2000a,b).

Capping the entire Finlayson Lake district, and unconformably overlying the rocks of the Wolverine succession, are Pennsylvanian-Permian (T. Harms, *in:* Plint and Gordon, 1997, p. 124) rocks of the Campbell Range

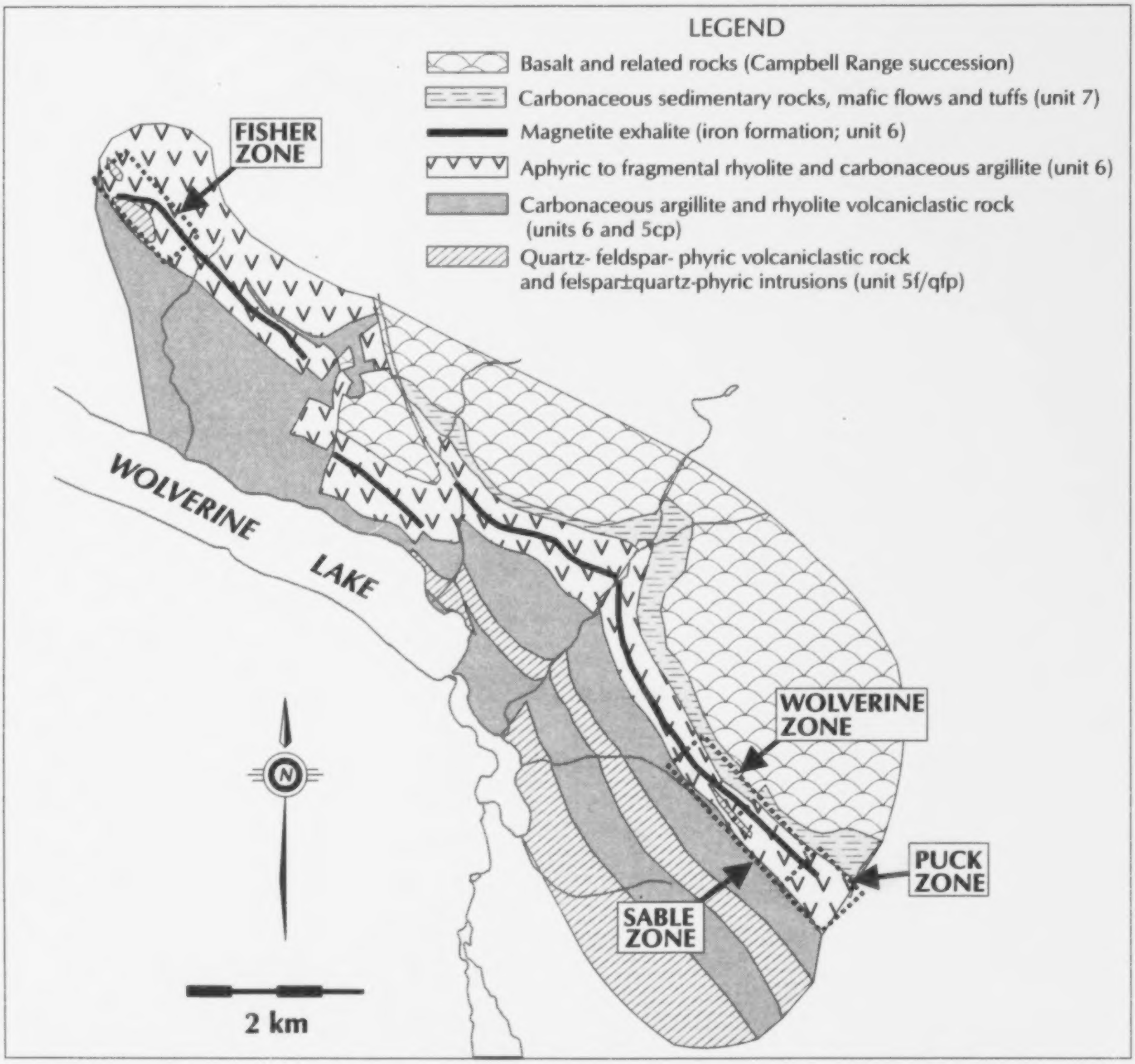
LEGEND
Basalt and related rocks (Campbell Range succession)
Carbonaceous sedimentary rocks, mafic flows and tuffs (unit 7)
Magnetite exhalite (iron formation; unit 6)
Aphyric to fragmental rhyolite and carbonaceous argillite (unit 6)
Carbonaceous argillite and rhyolite volcaniclastic rock (units 6 and 5cp)
Quartz- feldspar- phyric volcaniclastic rock and felspar±quartz-phyric intrusions (unit 5f/qfp)
FISHER ZONE
WOLVERINE
LAKE
WOLVERINE ZONE
PUCK ZONE
SABLE ZONE
N
2 km

Figure 3. *Geological map of Wolverine VHMS deposit area. Numbers of units in the map legend are from Murphy and Piercey (1998); CRS = Campbell Range succession. Map modified after Westmin Resources and Atna Resources (unpublished).*

succession (cf. Murphy, this volume; Fig. 2). This succession consists of largely clastic sedimentary rocks, pillowed to massive mafic lava flows, high-level diabase intrusive rocks, leucogabbroic intrusive rocks of MORB chemistry and chert-rich sedimentary rocks, that host numerous Cyprus-style VHMS occurrences (Mann and Mortensen, 2000; M. Baknes, *in:* Hunt, 1997; Pigage, 1997). Plint and Gordon (1997) and Murphy and Piercey (1999a,b,c) give more detailed descriptions of the geology of the Campbell Range succession.

GEOLOGICAL FEATURES OF PORPHYRIES ASSOCIATED WITH THE WOLVERINE VHMS DEPOSIT

Within the Wolverine VHMS deposit area, most intrusions are K-feldspar porphyritic and only a few are quartz-feldspar porphyritic. In all cases the intrusions are spatially associated with, and underlie, massive sulphide mineralization or iron formation (Wolverine/Lynx, Fisher, Sable and Puck zones; Fig. 3). Notably, to date significant massive sulphide accumulations have only been delineated in the Wolverine/Lynx zone; however, all zones contain iron formation and carbonate exhalite suggesting that they are part of the same hydrothermal system. The zones discussed in this paper are treated as representing parts of the same system and are distinguished partly on the geographic distribution of diamond drill holes outlined during exploration and delineation of the Wolverine VHMS system. Outlined below are the geological attributes of porphyritic intrusions within the four zones of the Wolverine VHMS system (cf. Fig. 3). Salient geological features of the intrusions are given in Table 1.

WOLVERINE/LYNX ZONE

Porphyritic intrusions associated with the Wolverine/Lynx zones and the Wolverine deposit are sill-like feldspar porphyritic intrusions (FPI; Fig. 4) with euhedral to subhedral 0.1-1 cm K-feldspar phenocrysts in a grey, siliceous fine-grained matrix; the phenocrysts comprise ~20% of the rock on average (Fig. 5). The upper contacts of intrusions are against black carbonaceous argillite, and for the most part are sheared due to Cretaceous deformation (cf. Murphy, 1998). Where the contacts are not sheared, the intrusions do not exhibit peperitic margins indicating they had minimal interaction with wet, unconsolidated sedimentary rocks. The lower margins of the intrusions are in contact with fine-grained, variably crystal-rich, felsic volcaniclastic rocks (tuffs). Most of the intrusions are sill-like in morphology (Fig. 4), ranging in true thickness from ~1 to 14 m, with an average thickness of ~7.5 m. These intrusions are located on average 20 m

***Table 1.** Outline of the salient geological features of porphyritic intrusions from different zones within the Wolverine VHMS system. Descriptions are outlined in zones from northwest to southeast.*

Zone	Fisher	Wolverine / Lynx	Sable	Puck
Intrusion Type[1]	FPI	FPI	QFP	FPI + QFP
Massive Sulphide?	minor	abundant	minor	minor
Exhalites	yes	yes	yes	yes
Upper Contacts	argillite and silicified argillite; partly sheared	argillite and silicified argillite; partly sheared	fine-grained felsic vol-aniclastic	FPI: siliceous to weakly siliceous argillite; QFP: argillite
Lower Contacts	med-fine grained felsic volcaniclastic	fine-grained felsic volcaniclastic ± argillite	fine-grained felsic volcaniclastic	fine-grained felsic volcaniclastic argillite
Alteration[2]	veinlets of py-ser-qtz ± chl; secondary black K-fsp	veinlets of py-ser-qtz ± chl; secondary black K-fsp	veinlets of py-ser-qtz -sph	veinlets of py-ser; py replacement in K-fsp; secondary black K-fsp

Notes

[1] FPI - feldspar porphyritic intrusion, QFP - quartz-feldspar porphyritic intrusion

[2] py - pyrite; ser - sericite; qtz - quartz; chl - chlorite; sph - sphalerite; fsp - feldspar

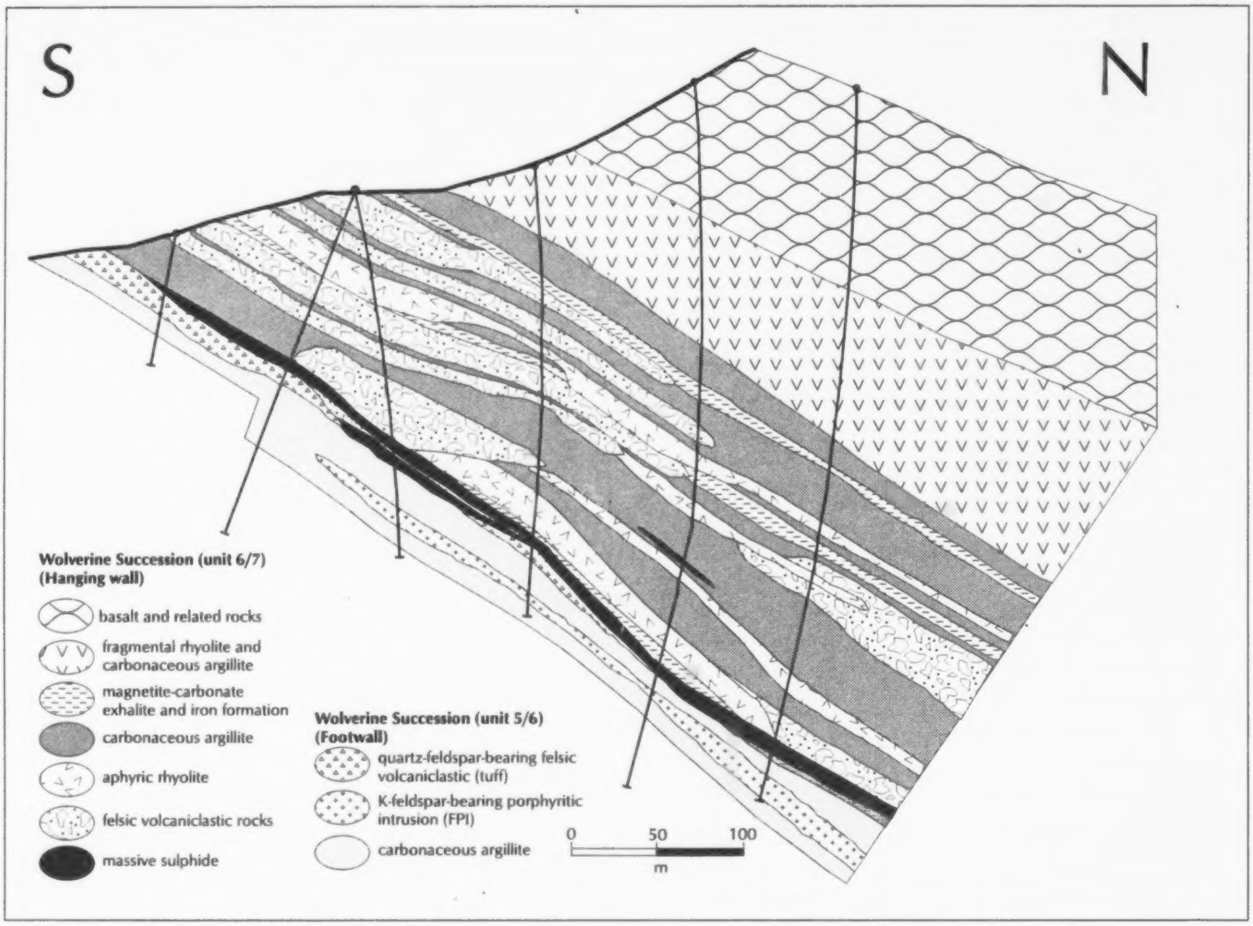
S
N
Wolverine Succession (unit 6/7)
(Hanging wall)
basalt and related rocks
fragmental rhyolite and carbonaceous argillite
magnetite-carbonate exhalite and iron formation
carbonaceous argillite
aphyric rhyolite
felsic volcaniclastic rocks
massive sulphide
Wolverine Succession (unit 5/6)
(Footwall)
quartz-feldspar-bearing felsic volcaniclastic (tuff)
K-feldspar-bearing porphyritic intrusion (FPI)
carbonaceous argillite
0
50
100
m

Figure 4. *Cross-section of 16250E of the Wolverine VHMS deposit, with outline of the size, shape and distribution of porphyritic intrusions within the Wolverine/Lynx zone and their relationship to massive sulphide mineralization and iron formation/carbonate exhalite. The sill-like morphology of the intrusions is typical of intrusions in all zones within the Wolverine VHMS deposit area. Figure modified after Bradshaw et al. (this volume). Abbreviations: Qtz – quartz; fsp – feldspar.*

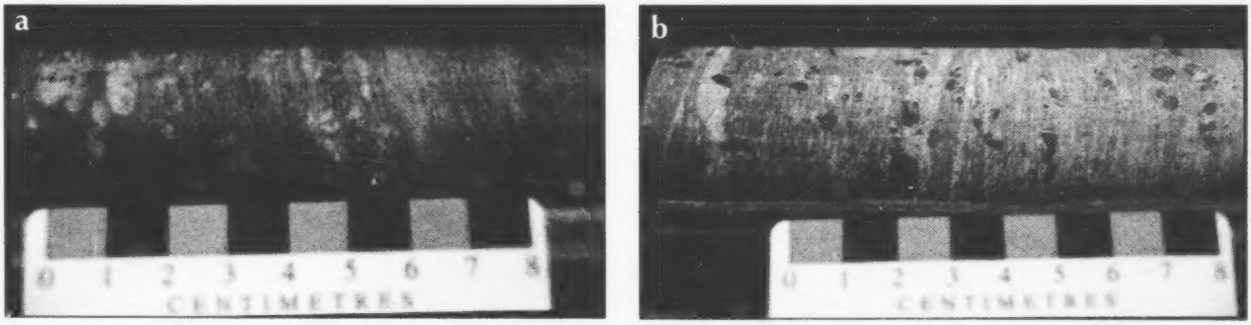
a
b
0 1 2 3 4 5 6 7 8
CENTIMETRES
0 1 2 3 4 5 6 7 8
CENTIMETRES

Figure 5. *a. Feldspar porphyritic intrusions from the Wolverine/Lynx zone with subhedral K-feldspar grains in a siliceous matrix. Note the dark grey to black crosscutting quartz-sulphide-sericite veinlets; b. partial to fully replaced K-feldspar grains with secondary black K-feldspar.*

below the massive sulphide mineralization in the Wolverine/Lynx zones (cf. Bradshaw et al., this volume).

The feldspar porphyritic intrusions of the Wolverine/Lynx zone are unaltered to weakly altered. The most common type of alteration within the FPI consists of a patchy distribution of partial to complete replacement of K-feldspar by grey to black secondary K-feldspar (as identified by X-ray diffraction at the Geological Survey of Canada; Fig. 5b). Within the porphyries veinlet-style alteration is less common than secondary K-feldspar. It consists of millimetre-scale veinlets of weak fine-grained sericite and quartz (Fig. 5a). Pyrite-quartz and pyrite-quartz-sericite veinlets commonly crosscut many of the samples; in a few samples chlorite-pyrite-quartz veinlets are present (e.g., Fig. 5a). The intensity of veinlet-style alteration commonly decreases with distance from the upper and lower contacts.

FISHER ZONE

The porphyritic intrusions of the Fisher zone have strong petrographic similarities to those from the Wolverine/Lynx zone. The intrusions are mostly feldspar porphyritic intrusions with some portions having minor quartz (QFP). Euhedral to weakly subhedral 0.1-1 cm K-feldspar phenocrysts make up ~20% of the rock within a grey fine-grained matrix (Fig. 6). Some QFP have 1-2 mm, quartz-filled amygdules. In one drill hole the edges of the FPI have rhyolite extrusive characteristics with autobrecciated rhyolite fragments and a less feldspar-phyric margin that grades inward into a more feldspar-rich interior, suggesting rapid quenching of the margin and slower cooling of the interior. As with intrusions associated with the Wolverine/Lynx zone, the Fisher zone intrusions appear to be at the same stratigraphic level having upper contacts with black argillite that lack peperitic textures; and the lower contacts are against fine-grained felsic volcaniclastic rocks (tuffs?). The average thickness of the intrusion varies from 1 m to ~50 m; however, there may have been considerable structural thickening within the nose of a Cretaceous fold (cf. Murphy, 1998); primary interpreted thicknesses are estimated to vary from ~1 to 14 m. The feldspar porphyritic intrusions from the Fisher zone are not associated with significant amounts of massive sulphide mineralization; however, they lie at a similar stratigraphic level, and are overlain by minor disseminated sulphide and iron-formation (cf. Peter et al., in prep.), inferring a correlation with the Wolverine/Lynx zone intrusions.

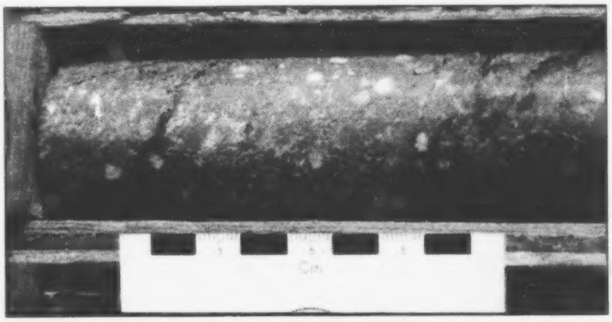

Figure 6. *Unaltered to weakly altered feldspar porphyritic intrusion from the Fisher zone with black to grey quartz-sericite-chlorite-sulphide veinlets cutting across it.*

The Fisher zone intrusions are relatively unaltered. Partial to complete replacement and patchy overprinting of feldspars by black, secondary K-feldspar is the prevalent type of alteration. The Fisher zone intrusions also contain minor veinlet-style alteration. This veinlet-style alteration consists of 1- to 7-mm-wide veins of pyrite-sericite-quartz±chlorite and is very similar to that in the Wolverine/Lynx zone, with a similar spatial distribution displayed in some diamond drill holes (Fig. 6).

SABLE ZONE

The Sable zone intrusions differ significantly from the Wolverine/Lynx and Fisher zone intrusions. All of the Sable zone intrusions are quartz-feldspar-porphyritic intrusions (QFP) with quartz and K-feldspar phenocrysts comprising ~20-30% of the rock within a grey to weak grey-green, fine-grained matrix (Fig. 7). Quartz phenocrysts are dark grey to black, glassy, eye-shaped, and 0.1-0.5 cm in diameter (Fig. 7). Potassic feldspar phenocrysts are less abundant than quartz phenocrysts and comprise ~5-10% of the rock as euhedral grains 0.1-0.5 cm in diameter (Fig. 7). The QFP have non-peperitic upper and lower contacts with fine-grained felsic volcaniclastic rocks. Intrusions within the Sable zone are 2-16 m thick and lie below minor amounts (~30 cm) of massive sulphide, which in turn are overlain by exhalative iron formation, similar to the other zones (cf. Peter et al., in prep.). However, given their distinctive petrographic characteristics and stratigraphic position these intrusions are not likely correlative to those in the Wolverine/Lynx and Fisher zones.

Only veinlet-style alteration is present in the Sable zone QFP and it is associated with 1- to 4-mm-wide veinlets of sericite-pyrite, pyrite-quartz±fine-grained sphalerite, and pyrite-sphalerite. In some samples sulphide veinlets constitute 5-10% of the rock.

PUCK ZONE

Both quartz-feldspar and feldspar-porphyritic intrusions are present in the Puck zone. Feldspar porphyritic intrusions are present in 2 drill holes and are similar to those in the Wolverine/Lynx and Fisher zones. These intrusions are 0.5-3.5 m thick and consist of euhedral, 0.1-2 cm diameter K-feldspar phenocrysts within a grey, fine-grained matrix (Fig. 8). The Puck feldspar porphyritic intrusions have non-pepperitic upper contacts with black argillite and lower contacts against fine-grained felsic volcaniclastic rocks, akin to feldspar porphyritic intrusions in other zones. A 25-m-thick QFP occurs in one drill hole and consists of 3-4 mm elliptical-shaped blue quartz and euhedral K-feldspar in a siliceous grey matrix. Upper and lower contacts of the QFP are similar to those of the feldspar-porphyritic intrusions. Both QFP and feldspar porphyritic intrusions are stratigraphically overlain by minor massive sulphide mineralization and iron formation (cf. Peter et al., in prep.), inferring a possible correlation to intrusions within the Wolverine/Lynx and Fisher zones.

Similar to intrusions in other zones, the alteration intensity is weak. Feldspar-porphyritic intrusions have some fine sericite-pyrite veins and notably the K-feldspar phenocrysts are partially to completely replaced by patchy secondary K-feldspar (Fig. 8). The QFP have minor disseminated pyrite throughout and some of the feldspars are incipiently replaced by pyrite. Both intrusion types have low-level alteration and mineralization.

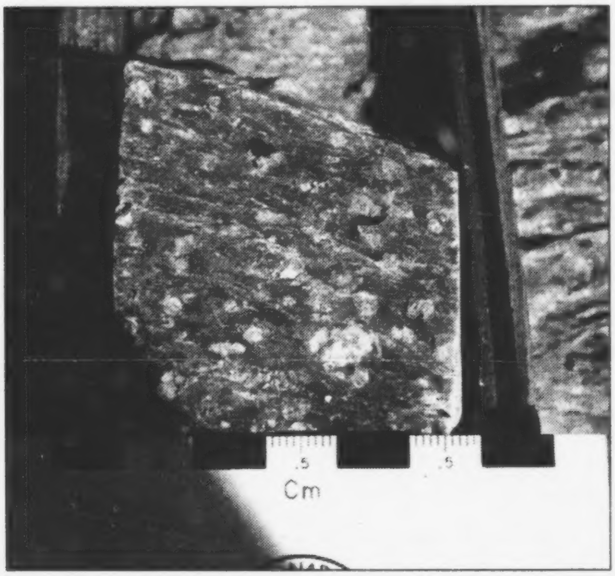

Figure 7. Sable zone quartz-feldspar porphyritic intrusion with darker grey quartz eyes and lighter grey K-feldspar. Note the smaller size of feldspar grains as compared to the Wolverine/Lynx and Fisher zones (Fig. 5).

DISCUSSION

The spatial proximity of high-level subvolcanic intrusions to massive sulphide mineralization and iron formation within the Wolverine VHMS deposit points to a passive (to possibly active) role of these intrusions in the genesis and localization of the Wolverine VHMS deposit. The following discussion will briefly address two questions, namely: 1) Are the porphyritic intrusions pre-, syn- or post-mineralization?; and 2) What is the significance of the porphyritic intrusions to the localization of sulphide mineralization?

PRE-, SYN- OR POST-MINERALIZATION EMPLACEMENT OF THE PORPHYRIES

The close spatial association of the porphyritic intrusions to massive sulphide mineralization and iron formation within the Wolverine deposit raises the question of whether the intrusions are of syn-, post- or pre-hydrothermal origin. Some possible evidence for a post-mineralization origin for the porphyritic intrusions is their non-peperitic upper margins and lack of other evidence for interaction with wet unconsolidated material (e.g., modification of bedding, etc.). This would suggest emplacement into solidified material and a likely non-

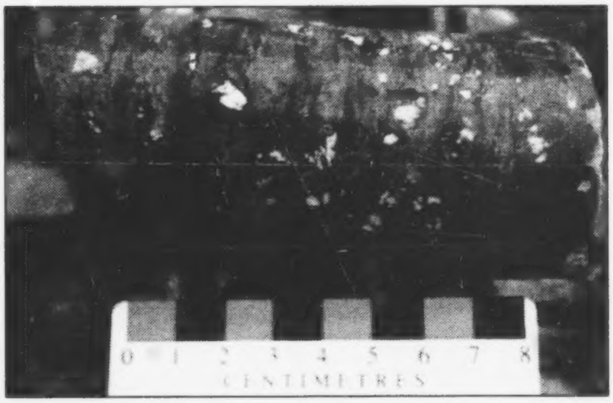

Figure 8. Puck zone feldspar porphyritic intrusion with variably broken K-feldspar grains with partial replacement by secondary K-feldspar.

syn-volcanic/syn-sedimentary and post-hydrothermal origin. It is notable, however, that many of the contacts between the intrusions and overlying argillites are sheared due to Cretaceous deformation, and much of the evidence for intrusion-sediment interaction may have been removed or obscured. Further evidence for a post-hydrothermal origin is quite strong. Firstly, the intrusive rocks within the deposit only occur stratigraphically below the massive sulphide mineralization or iron formation. Although this does not necessarily prove that they are not post-mineralization, the presence of interpreted VHMS-related alteration of the intrusions (e.g., sericite-chlorite-quartz veinlets), and crosscutting sulphide-bearing veinlets in the intrusions suggest that they were not emplaced after hydrothermal activity.

Determining the syn- or pre-mineralization timing of intrusion is less clear. A pre-mineralization origin is compatible with the presence of hydrothermal alteration and crosscutting sulphide veining. For example, the intrusions may have been emplaced prior to generation of the VHMS system and then subsequently altered as hydrothermal activity commenced to generate the Wolverine deposit and related iron formations. Similarly, geological evidence for a syn-mineralization history (syn-sedimentary/syn-volcanic in origin) for the intrusions (e.g., peperites, contorted bedding) is lacking and, at present, most evidence points to a pre-mineralization origin. Nevertheless, the spatial association of these intrusions to VHMS mineralization is significant (see below) and further facies mapping of the intrusion-sediment contacts is required to test the syn- versus pre-mineralization origin of these intrusions.

SIGNIFICANCE OF PORPHYRIES FOR LOCALIZATION OF SULPHIDE MINERALIZATION

The presence of porphyritic intrusions proximal to (~10-20 m below) the Wolverine VHMS deposit and iron-formation/exhalites is significant from a regional perspective. There are high-level intrusions outside of the Wolverine succession (e.g., Murphy and Piercey, 1999a); however, they are not as volumetrically condensed and are more regionally dispersed when compared to those proximal to the Wolverine VHMS system. The presence of these coherent magmatic rocks (i.e., flows and intrusions, not volcaniclastic or epiclastic) close to exhalative activity, and their relatively minor abundance elsewhere in the Wolverine succession, suggests that unique conditions prevailed proximal to the Wolverine deposit area that controlled the emplacement of these rocks. The authors suggest that the presence of coherent volcanic facies in the Wolverine deposit was likely controlled by synvolcanic structures (growth faults?). Furthermore, the structures that controlled the intrusion emplacement were also likely responsible for controlling the hydrothermal fluids that formed the Wolverine deposit and related exhalites. It is also notable that coherent aphyric rhyolitic flows (Fig. 4) that overlie the Wolverine massive sulphides are also restricted to the area proximal to the Wolverine deposit and have not been recognized, thus far, elsewhere in the district. It is possible that coherent facies (i.e., not volcaniclastic or epiclastic) felsic volcanic rocks may reflect proximity to volcanic vents and through-going structural conduits that allowed their emplacement. The authors acknowledge, however, that they have not yet documented facies changes, thickness variations or syn-volcanic dyking to support the proximity of the intrusions to syn-volcanic faults. Further mapping of thickness variations, and volcanic facies associated with the intrusions and coherent facies rocks is required to test this syn-volcanic-emplacement hypothesis.

The proximity of these intrusions to massive sulphide mineralization also suggests that they were possible heat and/or metal sources. The authors are presently unable to address whether these intrusions were the sources of metals and further data is required; however, some insight can be provided into the possibility of these intrusions as heat sources for hydrothermal circulation that formed the Wolverine deposit. When compared to many subvolcanic intrusive rocks in world-class VHMS districts (e.g., Flavrian-Noranda; Biedelman Bay-Mattabi; Cambrian granites-Mount Read; cf. Galley, 1996; Large et al., 1996), which are considered to be the heat and/or metal source for VHMS mineralization, the intrusions that constitute the footwall of the Wolverine system are volumetrically minor (i.e., 10s of m^2 rather than 10s of km^2). Therefore, the authors suggest that these intrusions alone are of insufficient size (see Fig. 4 as compared to Cathles, 1981, 1983; Barrie et al., 1999) to be the sole thermal control on the generation and maintenance of the hydrothermal system responsible for the Wolverine deposit . What the intrusions likely reflect, however, are 'leaks' from a larger underlying intrusive system that has yet to be identified that may have driven hydrothermal circulation. It is possible that a subvolcanic intrusive system akin to the Grass Lakes suite intrusions in the Kudz Ze Kayah unit underlies the Wolverine succession. However, the Wolverine succession has not been uplifted significantly, unlike the Kudz Ze Kayah unit and Grass Lakes succession (cf. Murphy and Piercey, 1999a). The lack of uplift may have prevented the surface expression of a deeper intrusive system to the Wolverine succession.

SUMMARY AND CONCLUSIONS

Initial results from our study of high-level subvolcanic porphyritic intrusions within the Wolverine VHMS deposit show that footwall intrusions are largely K-feldspar porphyritic with lesser quartz- and K-feldsparporphyritic intrusions. Most of the intrusions have non-peperitic upper margins against carbonaceous argillite (Wolverine/ Lynx, Fisher, Puck); however, some of the QFP intrusions have upper margins in contact with fine-grained volcaniclastic rocks (Sable); both have lower margins in contact with fine-grained volcaniclastic sedimentary rocks. These intrusions are located at variable distances (~10-20 m) below exhalative sulphide bodies or iron formation. For the most part, the intrusions are unaltered to weakly altered having sericite-quartz±chlorite±pyrite alteration and small mm- to cm-scale veinlets of quartz-sericite±chlorite±pyrite±sphalerite. The presence of alteration and mineralization within the intrusions suggests a pre- to syn-mineralization timing for their emplacement. The large number of coherent intrusive rocks proximal to the Wolverine deposit, and their relative scarcity elsewhere in the district, suggests that the emplacement of these intrusions may have been controlled by synvolcanic faults, which themselves controlled hydrothermal fluid flow. Although abundant, the volume of the intrusions is quite small (10s of m^2), and the authors suggest that the size of these intrusions was insufficient to have generated the hydrothermal fluid flux required to form the Wolverine deposit. However, the intrusions may represent 'leaks' (or apophyses?) from a larger intrusive system at depth that may have controlled the hydrothermal budget of the Wolverine deposit. The authors are presently uncertain of the role the intrusions have played in the metal budget of the Wolverine deposit, and this is the focus of ongoing research.

ACKNOWLEDGEMENTS

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Intrusive-breccia-hosted gold mineralization associated with ca. 92 Ma Tombstone Plutonic Suite magmatism: An example from the Bear Paw breccia zone, Clear Creek, Tintina gold belt, Yukon

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Stephens, J.R. and Weekes, S., 2001. Intrusive-breccia-hosted gold mineralization associated with ca. 92 Ma Tombstone Plutonic Suite magmatism: An example from the Bear Paw breccia zone, Clear Creek, Tintina gold belt, Yukon. *In:* Yukon Exploration and Geology 2000, D.S. Emond and L.H. Weston (eds.), Exploration and Geological Services Division, Yukon, Indian and Northern Affairs Canada, p. 347-353.

ABSTRACT

The Bear Paw breccia zone is located at the Clear Creek property in the Tintina gold belt, central Yukon Territory. Gold mineralization occurs in hydrothermal breccias with stockwork quartz + potassium-feldspar + sulphide veins that overprint earlier intrusive and tectonic breccias. Grades of up to 2.3 g/t gold over 31.8 m have been intersected in recent drilling. The Bear Paw breccia zone is 1.5 km from any significant-sized granitoid stock and thus is indicative of the high potential for gold mineralization outboard of Tombstone Plutonic Suite stocks.

RÉSUMÉ

La zone bréchique de Bear Paw se trouve sur la propriété de Clear Creek, dans la ceinture aurifère de Tintina, dans le territoire du Yukon. La minéralisation aurifère dans la zone est associée aux brèches hydrothermales composées de filons de quartz + feldspath potassique + sulfures qui se surimposent sur des brèches intrusives et tectoniques plus anciennes. Les sondages ont rencontré des teneurs d'or allant jusqu'à 2,3 g/t d'or sur 31,8 m. La zone bréchique de Bear Paw se trouve à 1,5 km de tout stock granitique de taille significative et indique le potentiel élevé de minéralisation aurifère à l'extérieur des stocks du cortège plutonique de Tombstone.

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INTRODUCTION

The Bear Paw breccia zone is located at the Clear Creek property, in the Tintina gold belt, central Yukon Territory (Fig. 1). Recent drilling has defined significant gold grades hosted predominantly by intrusive and tectonic breccias associated with ca. 92 Ma Tombstone Plutonic Suite (TPS) magmatism.

LOCAL GEOLOGY

Highly deformed, dominantly clastic metasedimentary rocks of the Neoproterozoic to Early Cambrian Hyland Group underlie the Clear Creek area. Numerous TPS stocks, dykes and sills with compositions varying from quartz monzonite to granite, granodiorite and diorite were emplaced into Hyland Group country rocks at ca. 92 Ma (Murphy, 1997; Fig. 2). Temporally associated auriferous quartz-sulphide veins occur within, and surrounding, most of the larger stocks (Marsh et al., 1999, 2000).

Three dominant structural trends have been identified in the area (Stephens et al., 2000; Stephens and Mair, 2000):

1. South- to south-southeast-striking, steeply dipping, mostly sinistral faults, shear veins and granitoid dykes.
2. East- to east-southeast-striking, steep fracture zones, granitoid and lamprophyre dykes and a dominant set of auriferous quartz-sulphide veins (Marsh et al., 1999, 2000).

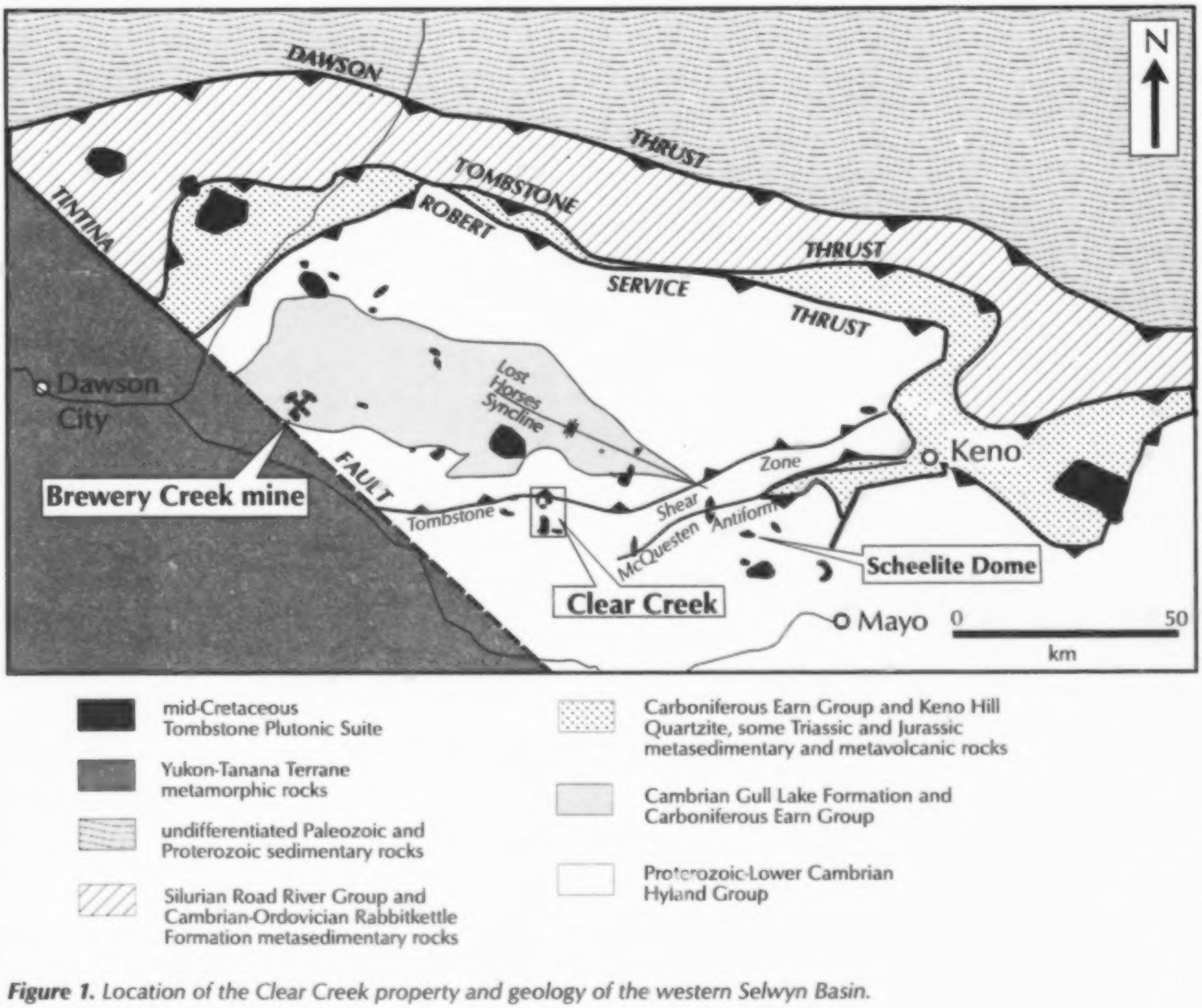
DAWSON
THRUST
TOMBSTONE
THRUST
ROBERT
SERVICE
THRUST
TINTINA
FAULT
N
Dawson City
Brewery Creek mine
Lost Horses Syncline
Tombstone
Shear
Zone
McQuesten Antiform
Keno
Scheelite Dome
Clear Creek
Mayo
0
50
km
mid-Cretaceous Tombstone Plutonic Suite
Yukon-Tanana Terrane metamorphic rocks
undifferentiated Paleozoic and Proterozoic sedimentary rocks
Silurian Road River Group and Cambrian-Ordovician Rabbitkettle Formation metasedimentary rocks
Carboniferous Earn Group and Keno Hill Quartzite, some Triassic and Jurassic metasedimentary and metavolcanic rocks
Cambrian Gull Lake Formation and Carboniferous Earn Group
Proterozoic-Lower Cambrian Hyland Group

Figure 1. *Location of the Clear Creek property and geology of the western Selwyn Basin.*

3. Northeast- to north-northeast-striking, steep fracture zones with a lack of dykes and veins.

The following four main styles of gold mineralization are recognized at Clear Creek, two of which occur in the Bear Paw breccia zone:

1. East- to east-southeast-striking, sheeted, auriferous quartz sulphide veins occurring mostly within larger TPS stocks, (e.g., Rhosgobel, Pukelman, Eiger stocks).
2. Silicified fault zones in both south to southeast and east to east-southeast orientations (e.g., Contact zone).
3. Intrusive breccias with stockwork, auriferous quartz-sulphide veins (e.g., Bear Paw breccia, Saddle Stock).
4. Calc-silicate rocks with replacement/skarn-style mineralization (e.g., Bear Paw breccia).

EXPLORATION HISTORY

The Clear Creek area has produced about 130,000 ounces (4 million grams) of placer gold since the turn of the century (Allen et al., 1999), with hardrock claims dating back to almost as far as the placer records. Modern day exploration work began in the late 1970s and early 1980s with companies investigating the area for tungsten and tin. In the mid 1980s, exploration work shifted to the hardrock gold potential and concentrated on mineralization mostly hosted within the numerous TPS intrusive bodies on the property. Exploration focused on low-grade, high-tonnage, granitoid-hosted, sheeted-vein-style mineralization similar to that currently being mined at Fort Knox, Alaska. Work conducted on the property since the mid 1980s included geological mapping, soil sampling, trenching, ground and airborne magnetic and radiometric surveys and drilling.

DISCOVERY OF THE BEAR PAW BRECCIA

In the mid 1990s, Kennecott Canada Ltd. collected soil samples along the road that they constructed on the ridge separating Clear Creek and Left Clear Creek. Anomalous gold results encouraged Newmont Exploration Limited to undertake a contour-soil geochemical survey to further define the gold-bismuth anomaly.

Follow-up prospecting by geologists Mike Stammers and Richard Gorton (Newmont) found float of mineralized breccia that they considered the source of the gold. Geophysical surveys showed that the gold-bismuth soil anomaly is associated with a magnetic low and potassium high, and a south- to southeast-trending VLF (very low frequency) anomaly.

In 1998, Newmont Exploration Limited completed a contour soil geochemical survey on the ridge that separates Clear Creek and Left Clear Creek (Fig. 3). A gold and bismuth anomaly that is associated with a magnetic low and potassium high was identified. A south- to southeast-trending VLF anomaly was subsequently identified just east of the soil geochemical anomaly. This area was to become the Bear Paw breccia zone.

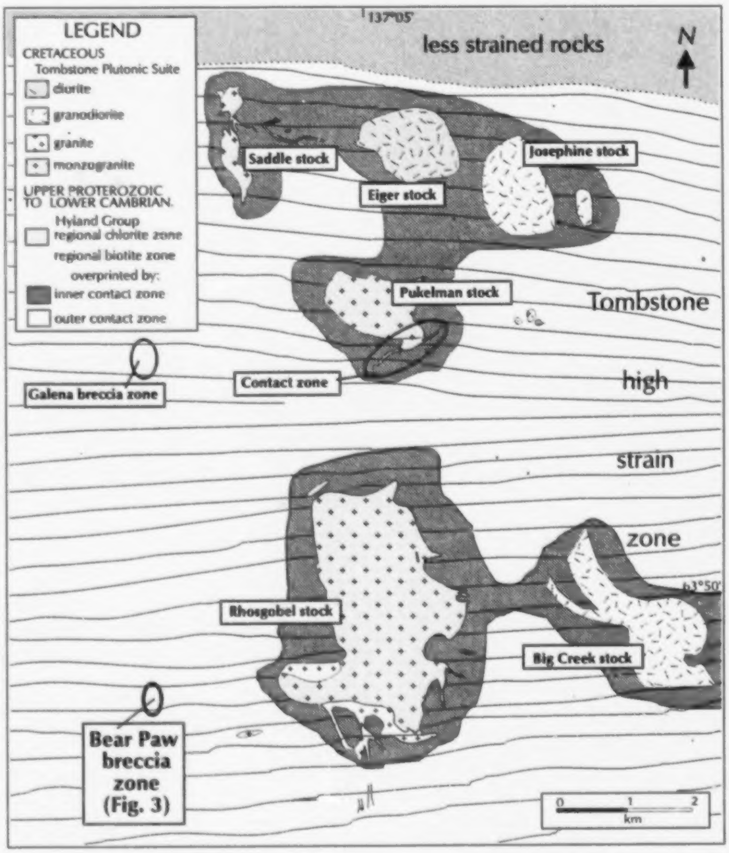
LEGEND
CRETACEOUS
Tombstone Plutonic Suite
diorite
granodiorite
granite
monzogranite
UPPER PROTEROZOIC TO LOWER CAMBRIAN
Hyland Group
regional chlorite zone
regional biotite zone
overprinted by:
inner contact zone
outer contact zone
137°05'
less strained rocks
N
Saddle stock
Josephine stock
Eiger stock
Pukelman stock
Tombstone
high
strain
zone
Contact zone
Galena breccia zone
Rhosgobel stock
63°50'
Big Creek stock
Bear Paw breccia zone (Fig. 3)
0
1
2
km

Figure 2. Simplified geology of the Clear Creek area displaying the location of Tombstone Plutonic Suite (TPS) stocks. The Bear Paw breccia zone (Fig. 3) is 1.5 km from the nearest significant exposed TPS stock in an area covered by soil and colluvium.

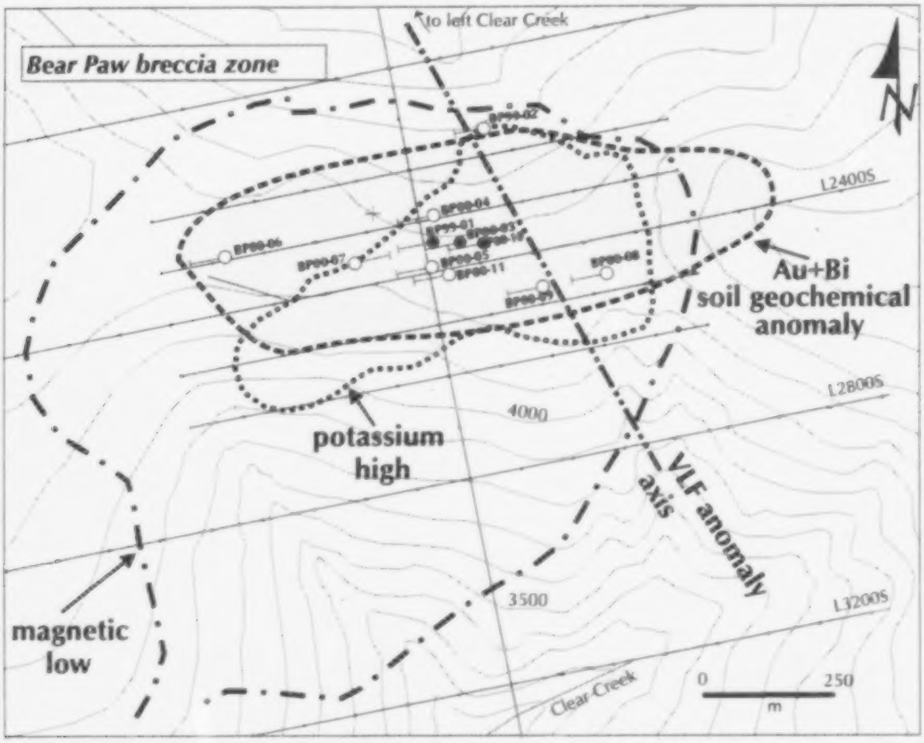
to left Clear Creek
Bear Paw breccia zone
BP00-02
BP00-04
BP99-01
BP00-03
BP00-10
BP00-06
BP00-07
BP00-05
BP00-11
BP00-08
BP00-09
L2400S
Au+Bi soil geochemical anomaly
L2800S
4000
potassium high
VLF anomaly axis
3500
L3200S
magnetic low
Clear Creek
0
250
m

Figure 3. *Summary map of drilling, geophysical and geochemical surveys conducted on the Bear Paw breccia zone. The two most prominent mineralized structural trends on the property are consistent with the south- to southeast-trending VLF anomaly and the east to east-southeast trend of the geophysical and geochemical anomalies. Contour spacing is 100 ft.*

In 1999, Redstar Resources Corporation completed a detailed soil-sampling program over the Bear Paw breccia zone in addition to two short diamond drill holes. Soil sampling defined a broad, east-trending gold and bismuth anomaly 900 x 400 m. The two drill holes intersected wide zones of hydrothermal breccia with gold mineralization. The discovery hole, BP99-01, returned 2.0 g/t over 26.7 m and was the first indication of the economic potential of the zone.

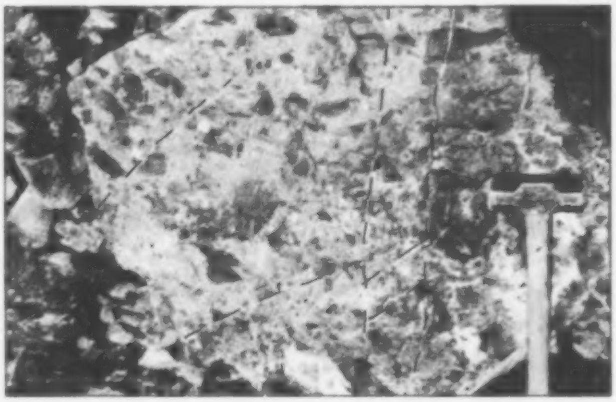

Figure 4. *Veined intrusive breccia from the Saddle stock. The dark fragments are mostly phyllite and the matrix is porphyritic quartz monzonite. The intrusive breccia is cut by mineralized quartz + potassium feldspar veins in two distinct orientations highlighted by dashed lines.*

BEAR PAW GEOLOGY

Drilling during the 1999 and 2000 exploration programs confirmed the presence of a large area of gold mineralization centred on an area of shallowly dipping, irregularly shaped, granitic sills and/or dykes, and associated intrusive breccia. These intrusive bodies and surrounding Hyland Group rocks formed a favourable zone for further fracturing and the introduction of mineralizing fluids to create a stockwork of quartz + potassium-feldspar + sulphide + gold veins.

Breccia types within the Bear Paw zone are divided into the following four categories on the basis of genesis:

1. Intrusive breccia: angular phyllitic and psammitic clasts in a matrix of medium-grained granite *(sensu lato)* (Fig. 4).
2. Tectonic breccia: angular clast-supported breccia dominated by phyllite and psammite with rare granitic clasts.

3. Hydrothermal breccia (Au): stockwork of quartz +' potassium-feldspar + sulphide + gold veins that overprints both the intrusive (1) and tectonic (2) breccias. Higher vein densities generally occur in zones where intrusive breccia and granodiorite sills or dykes are dominant. Many of the veins are 'breccia veins' and contain clasts of Hyland Group rocks.
4. Late hydrothermal breccia: irregular, thin, quartz–carbonate-pyrite veins with associated strong, pervasive, sericite/clay alteration of wallrocks. This phase overprints breccia types (1), (2) and (3) and is concentrated around fault zones.

The south- to southeast-trending Bear Paw fault zone has the strongest structural control on the Bear Paw breccia zone. A number of the faults intersected in drilling contain clay gouge, and cut granitic sills and/or dykes and intrusive breccia. There also appears to be some east-trending controls on the mineralization expressed in magnetic, geochemical and potassium anomalies (Fig. 3). In drill-core, the orientation of quartz + potassium-feldspar + sulphide + gold veins is consistent with the property-wide, roughly south- to southeast- and east-trending vein sets.

There is a continuous spatial zoning from sparse quartz + potassium-feldspar veining, to stockwork, to silica-flooded breccia zones (Figs. 5 and 6). Sulphide content in quartz veins is typically less than 2% and includes pyrite, pyrrhotite and chalcopyrite, with minor arsenopyrite, bismuthinite and gold. The best gold grades are associated with zones of granitic and intrusive-breccia-dominant hydrothermal breccias with visible bismuthinite. Zones of phyllite-dominant hydrothermal breccia with significant pyrrhotite, pyrite and chalcopyrite, however, returned only slightly elevated gold grades. A number of semi-massive quartz-sulphide veins up to 1 m wide were intersected and returned grades of 8-22 g/t gold (Fig. 7).

Several horizons of calc-silicate rocks with replacement pyrrhotite-pyrite-chalcopyrite mineralization were identified within the zone. All of these horizons are associated with elevated gold grades. Intercalated calc-silicate rocks and phyllite sections up to 10 m wide, grading 1.0 g/t gold were intersected in the drilling.

Redstar Resources Corporation completed nine diamond drill holes during the 2000 exploration season. All holes were drilled in the area of the Bear Paw breccia zone and all intersected varying amounts of breccia and gold mineralization. The best results were obtained from section 2350 m S, where hole BP00-03 returned

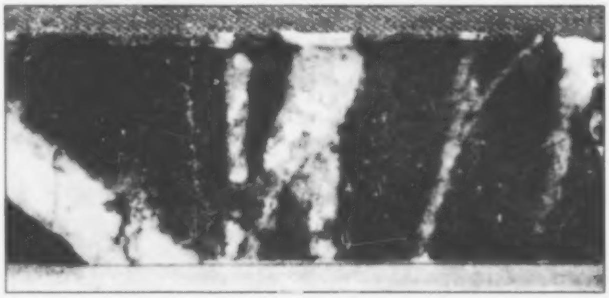

Figure 5. *Granitic-dominant stockwork/hydrothermal breccia displaying two distinct vein orientations. This style of breccia hosts most of the gold mineralization in the Bear Paw breccia zone.*

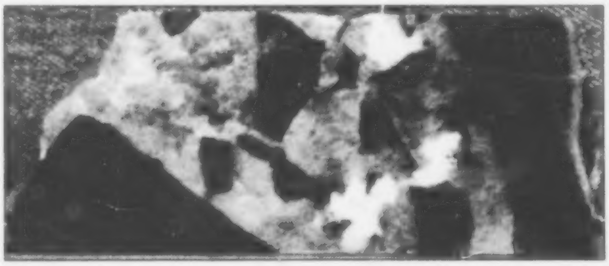

Figure 6. *Hydrothermal breccia vein in phyllite. Vein mineralogy is similar to that in Figure 5, but typically contains much lower gold grades than the granitic-dominant and heterolithic zones. The white mineral is potassium feldspar.*

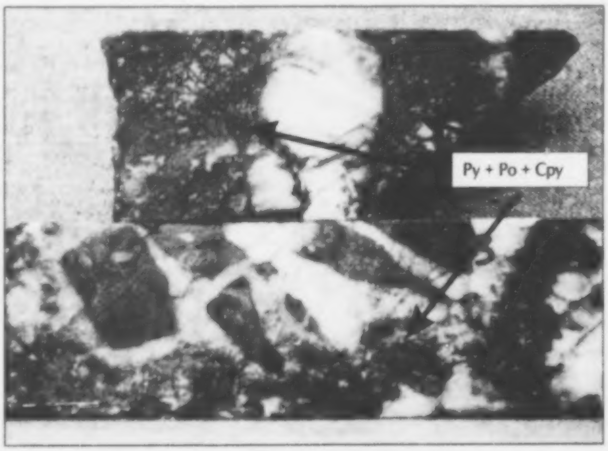

Figure 7. *Semi-massive sulphides in heterolithic hydrothermal breccia. The sulphides are pyrrhotite (Po), pyrite (Py) and chalcopyrite (Cpy), with minor arsenopyrite and bismuthinite. Gold grades within these veins range from 8-22 g/t gold.*

2.0 g/t Au over 34.8 m and hole BP00-10 returned 2.3 g/t Au over 31.8 m (Fig. 8).

CONCLUDING COMMENTS

The Bear Paw breccia zone is covered entirely by overburden and was discovered primarily by geochemical and geophysical surveys. Gold mineralization occurs in hydrothermal breccia that overprints earlier intrusive and tectonic breccias. The best zones of mineralization occur in areas dominated by granitic sills and/or dykes and intrusive breccia of the Tombstone Plutonic Suite (TPS). These areas have provided the best competency contrasts for fracturing resulting in enhanced rock permeability conducive to high fluid fluxes and consequently gold mineralization. Furthermore, high fluid pressures are indicated by the presence of mineralized breccia veins containing phyllite clasts hosted wholly within granite.

The Bear Paw breccia zone is situated 1.5 km from the nearest significant-sized stock and therefore indicates the high potential for structurally controlled gold mineralization significantly outboard from granitoid stocks throughout the entire TPS belt.

Soil geochemical sampling in 1999 and 2000 defined an area 1300 by 400 m that is anomalous in gold and bismuth. Drilling to date has tested only a portion of this anomaly. The wide zones of breccia-hosted gold mineralization intersected in 1999 and 2000 drilling programs indicate the area has the potential to host a large tonnage, near-surface gold resource.

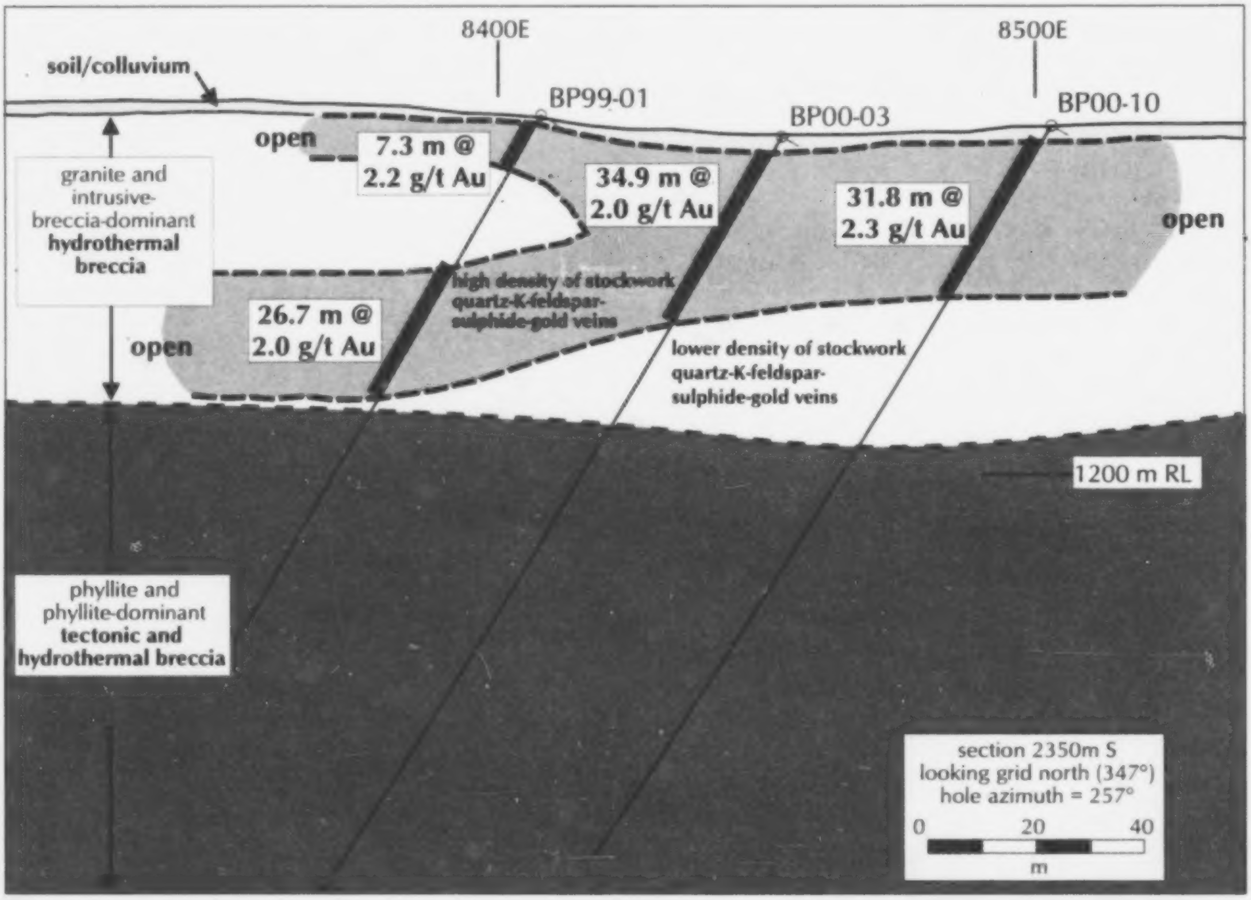
8400E
8500E
soil/colluvium
BP99-01
BP00-03
BP00-10
open
7.3 m @ 2.2 g/t Au
34.9 m @ 2.0 g/t Au
31.8 m @ 2.3 g/t Au
open
granite and intrusive-breccia-dominant hydrothermal breccia
high density of stockwork quartz-K-feldspar-sulphide-gold veins
26.7 m @ 2.0 g/t Au
open
lower density of stockwork quartz-K-feldspar-sulphide-gold veins
1200 m RL
phyllite and phyllite-dominant tectonic and hydrothermal breccia
section 2350m S
looking grid north (347°)
hole azimuth = 257°
0
20
40
m

Figure 8. Simplified 2350 m S cross-section showing the economic gold grades within an apparently flat zone (on section) dominated by granite and intrusive breccia. Location of drill holes is shown in Figure 3.

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